PROSIECT
CARTREFI O
BREN LLEOL

THE
HOME-GROWN
HOMES
PROJECT

Building Performance Evaluation Guide

Cefnogir y prosiect hwn gan Gronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig
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FOREWORD

By Fionn Stevenson

Housing is responsible for 78% of all the territorial carbon emissions from the UK built environment (BEIS statistics 2018). At the same time, the performance gap between expected carbon emissions from new housing and what actually happens is often shockingly underestimated. It's a sobering fact that we need to reduce all these emissions to net zero by 2050 according to government targets, and a lot sooner according to many respected NGOs.

How did this happen? How could there be so much ignorance about the reasons for this vast performance gap? And how are we going to reduce the gap in time? One reason it's there, is that no-one bothered to find out what the gap was, and so housing development in the UK continued for decades in ignorance of the design and construction failures mounting up.

Thankfully, we now have an organisation like Woodknowledge Wales, which is pioneering a new way of thinking, taking account of real performance and dealing with carbon emissions in the round by designing every aspect of a holistic and ecological circular economy to produce genuinely net zero carbon housing. This organisation is committed to making sustainable, affordable, and healthy housing that is fit for purpose and really does what it says on the tin.

This new guide is part of that way of thinking. It explains how to carry out successful and effective building performance evaluation of new homes to provide essential feedback for design validation and improvement. It provides much needed support for policymakers, housing developers, clients, contractors and design teams alike to help them navigate through the various methods needed to build up a true picture of housing performance – one that takes account of people and processes as well as buildings. It is the first of its kind and is destined to reach all key housing organisations not only in Wales, but across the whole of the UK.

Over the years there have been various POE guides produced, mainly for the non-domestic sector. The really useful thing about this one is that it is deliberately targeted at new build housing and is put together in a thoroughly accessible way with a 'tool pack' that allows the user to quickly learn the basics. At the same time, the guidance provides a clear road map which moves from essential BPE methods to more detailed methods where needed, taking the user on a journey of understanding the BPE process in a thoroughly systematic manner.

Woodknowledge Wales is to be commended on producing this guide, which draws on the expertise of the very best in the business. My hope is that this guide finds its way into every housing organisation's computer and onto every housing building site, to help clients, design teams and contractors produce the best possible housing that they can by understanding what is really going on.

Fionn Stevenson is Professor of Sustainable Design at the Sheffield School of Architecture, Chartered architect and Building Performance Evaluator. She is also Campaigns Director for the Building Performance Network UK. She is deeply committed to developing regenerative architecture to address the ongoing climate emergency.

EXECUTIVE SUMMARY

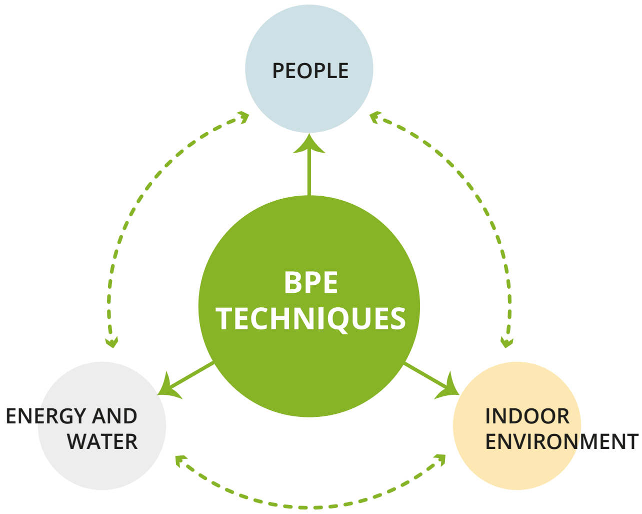
WHY BUILDING PERFORMANCE EVALUATION (BPE) IS NEEDED

There is little BPE currently happening routinely on projects, and new homes often fail to meet low-energy targets, and to satisfy residents with fundamental issues such as ease of use, summer comfort and energy costs. A step change is needed to transition to net zero carbon while making our homes comfortable, healthy and enjoyable. We need more BPE, and more learning from previous BPE.

WHAT IS BPE? APPROACH IN THIS GUIDANCE

This guidance recommends a “core” BPE scope for clients and project teams wanting to understand and improve the performance of their homes. This provides a holistic look at performance, including people, the indoor environment, fabric performance, energy use and water use. It highlights how BPE techniques can work together, and the interactions between energy performance, people, and the indoor environment.

This core BPE scope limits the involvement of experts and expensive equipment to where it is absolutely needed, often when already required for regulations. Instead, the aim is to embed building performance throughout the project stages and empower project teams to deliver high performance.



REGULATORY REQUIREMENTS

Minimum requirements for checks at completion, commissioning and documentation

No requirement in use, unless triggered by serious concerns

CORE BPE

- Design and documentation review
- Commissioning
- Handover review
- Site visits

- Energy strategy review
- Airtightness review, site checks & tests
- Thermal bridging & moisture review and site checks
- Early stage overheating analysis (GHA)
- Acoustic checks & testing of ventilation system

- Energy use audit
- Water use audit
- User surveys

DETAILED BPE

If needed, following core BPE

EXECUTIVE SUMMARY

HOW THE GUIDANCE WORKS

The "tool pack" provides an entry point to BPE activities and how to apply them throughout a project life; it is meant for day-to-day use on projects:

- Project timeline and prompt sheets for BPE actions at each project stage
- Client sheet to record performance objectives and identify associated BPE techniques to follow whether they've been achieved
- BPE technique one-pagers: an overview of each BPE technique, its purpose, how to procure it, and how and when to apply it.

Additional guidance on all featured BPE techniques is provided in the guide itself, including illustrations, references etc.

TOOL PACK:
Entry point Overview Day-to-day use

CLIENT SHEET
Set performance objectives & identify relevant BPE to check they are achieved.

TIMELINE + 4 PROJECT STAGE PROMPT SHEETS
- Design stage
- In construction
- Completion and handover
- In use

MAKING SENSE OF IT ALL
How to interpret BPE results as a whole, gain a holistic view of performance, draw recommendations and identify next steps.

BPE TECHNIQUE ONE PAGERS
What it's about, why do it, how to go about it, who to involve, what to do with the results.

GUIDANCE:
Background to BPE, more detail, examples, references etc.

INTRODUCTION
What is BPE, why it is useful, how to go about it

SETTING PERFORMANCE OBJECTIVES
i.e. what BPE results will be checked against

EMBEDDING BPE AT EACH STAGE WHAT TO DO WITH THE RESULTS?

CORE BPE
- Design and documentation review
- Handover review
- Early stage overheating analysis (GHA)
- Energy strategy review
- Thermal bridging and moisture review
- Site inspections and visits
- Airtightness review, checks and tests
- Commissioning
- Acoustic checks and testing of ventilation system
- Energy use audit
- Water use audit
- User surveys

DETAILED BPE
- Co-heating
- Thermography surveys (& spot checks)
- IEQ monitoring (& spot checks)
- Overheating analysis (dynamic modelling)
- Energy monitoring
- Energy modelling
- Water monitoring
- Thermal bridge analysis
- Hygrothermal analysis e.g. WUFI

SECTION

01

INTRODUCTION

INTRODUCTION: WHAT AND WHO THIS GUIDANCE IS FOR

1.1 AUDIENCE AND PURPOSE OF THIS GUIDE

This guidance is aimed at housing clients, and anyone interested in Building Performance Evaluation (BPE). It is aimed at non-specialists who want to evaluate and improve the performance of homes.

Its purpose is to provide an introduction to applying BPE in practice on projects, with:

- information for clients and project managers to gain an overview of the benefits of BPE, what the main BPE techniques can do, how to procure it, and the main activities to plan throughout a project from design to occupancy
- guidance on the main BPE techniques available
- “tools” for day-to-day use on projects, complemented by more detailed guidance, examples and references.

This guidance addresses the operational performance of homes. Other performance objectives for the project may be set, such as embodied carbon, the environmental impact of construction materials, quality of external spaces, social value from the project etc. – this is not considered in this guidance[1].

1.2 WHY BPE

In an ideal world a well designed and built home would not need to be checked, but to err is human and compromising for speed or struggling to make complex details work in the reality of a construction site are not uncommon. Routine pressure testing has led to increased levels of achieved air tightness, and other techniques can have similar benefits in terms of quality control, consistent performance and fewer complaints.

A recent large survey of what people want from their homes showed that what most matters is the basics: homes that are comfortable, and easy and affordable to run and maintain. Unfortunately, the survey also showed that these priorities are often not met: in only half of the cases, did respondents said that their home got these basics right (ref: Design Council, 2020 – see below).

Being fit for purpose

1  **1 A home that is affordable to run so I can still live a comfortable life**

2  **2 A home that gets the basics right**

3  **3 A home where I don’t have to worry about everything working as it should**

These principles represent some of the most basic physical and emotional requirements people have of their homes, which collectively allow them to go about their lives with ease, and which are important to almost everyone, regardless of demographics or region. Homes are affordable, they get the basics right (such as having a comfortable internal environment) and they don’t make people worry about everything working as it should.

“What people want from their homes in the future is informed by what they have at the moment – but many of the things which are most important to people in the future are missing in their current homes.”

“Only 56% report that their home gets the basics right”.

*(Source: Design Council, **Home of 2030 report**, 2020)*

[1] Download Home Grown Homes document embodied carbon pack ***here***.

INTRODUCTION

Applying BPE on projects, and integrating it into the whole delivery, management and learning cycle, can have multiple benefits:

- Reducing energy consumption and carbon emissions
- Reducing energy costs for inhabitants
- Improving comfort for inhabitants, and providing healthier environments
- Improving overall expertise and competence of project teams
- Pre-empting future regulations, as trends point towards more competence, better building performance, and more attention to actual in-use performance rather than design and as-built targets.

Added to these benefits, much of the core BPE recommended in this guidance is not especially time-consuming, expert or expensive; in many cases successful BPE hinges on setting the right targets, communicating clearly, paying attention to key issues throughout the design, build and in-use, asking the right questions of the right people along the way, and taking account of their answers.

1.3 WHAT IS BUILDING PERFORMANCE EVALUATION (BPE)

BPE covers a range of tools and techniques that can help determine how well a building and its elements are performing, and helps diagnose the problem when performance falls short of expectations.

Effective BPE starts at the briefing and design stage, by setting objectives and identifying lessons from previous projects. It follows through with regular checks, reviews and tests throughout the design and build and through into occupation. In short, BPE covers the following:

- Design stage: predicting the performance and informing the design
- Construction: checking implementation
- Completion and handover: checking as-built vs objectives
- Occupancy: checking in-use performance vs objectives, monitoring and assessing
- At each stage: gathering lessons for future projects, to ensure continuous learning and improvements.

When looking at occupants, BPE is concerned with all “users” of a building i.e. the inhabitants, but also anyone else who may work in, visit or look after the building e.g. building management or facilities management (FM team). There is little BPE currently happening routinely on projects, and a step change is needed if we are to improve the performance of our homes, to transition towards net zero carbon while keeping them comfortable, healthy and enjoyable for inhabitants.

This guidance therefore takes the following approach:

- **“Core BPE”:** this is the recommended scope for clients and project teams wanting to engage in a BPE exercise to understand the performance of their homes. This provides a holistic look at performance, including people, internal environmental quality (IEQ), fabric, energy use and water use, but should require the involvement of experts and specialist expensive equipment only where absolutely required and typically, when there is already an associated regulatory requirement (e.g. commissioning, blower door test for airtightness). The aim is to improve performance overall, and gradually raise the ability of professionals to understand and design for building performance.
- **“Detailed BPE”:** these include techniques which are only recommended if triggered by findings in the initial Core BPE exercise, or in particular circumstances (e.g. research purposes).

Important note: at the time of writing, co-heating tests are the main accepted method for measuring heat transfer coefficients (HTC), and they are covered as Detailed BPE in this guidance. However, the BEIS SMETER trials are evaluating options which would, if successful, provide measurements of the HTC in an easier, cheaper and less intrusive way. If this was the case, such tests could usefully be part of a core BPE exercise. Results from the SMETER trials are expected Q2 2021. In the meantime, such tests are covered as Innovative BPE techniques, in Section 6.

INTRODUCTION

REGULATORY REQUIREMENTS	CORE BPE	DETAILED BPE
• Attention to thermal bridging (Part C) • Provision of O&M documentation • Commissioning at completion (Part L) • Airtightness testing at completion (blower door test) (Part L) • Acoustic testing at completion No requirement in use, unless triggered by serious concerns e.g. Housing Health & Safety Rating System (HHSRS) in private rented homes	• Design and documentation review • Commissioning • Handover review • Site visits • Energy strategy review • Airtightness review, site checks & tests • Thermal bridging & moisture review and site checks • Early stage overheating analysis (GHA) • Acoustic checks & testing of ventilation system (if possible - Thermography spot checks) (if possible - IEQ spot checks, short-term monitoring) • Energy use audit • Water use audit • User surveys	• Co-heating • Thermography survey • Indoor Environmental Quality monitoring • Overheating analysis (dynamic modelling) • Energy monitoring • Energy modelling • Water monitoring • Thermal bridge analysis • Hygrothermal analysis e.g. WUFI PLUS More detailed BPE if need identified by the above e.g. detailed analysis of plant performance, focus groups, interviews, ...

It is really important to understand that while each BPE technique provides useful information on particular aspects of building performance, each provides only a particular angle and its results on their own could be mis-interpreted. Operational building performance covers energy performance, indoor environmental quality, and how well the building works for the people who occupy and use it. These three aspects matter equally, and they are closely linked. The real value from BPE is obtained when results from each technique are carried out and analysed not only individually, but in the round. This is why, while guidance is provided on each BPE technique individually, the guidance also refers to associated techniques, and provides recommendations on how to look at building performance altogether – see > section 3.5 ***Making Sense of it All***.

1.4 PRIVACY AND ETHICAL CONSIDERATIONS

Carrying out BPE at the in-use stage, i.e. when homes are occupied, has important privacy and ethics implications:

- The BPE exercise itself will always involve some level of disruption to residents, and may (especially in the case of detailed BPE) lead to interventions on the fabric and services of the homes, some of them temporary or minor (e.g. marks left on walls after sensors are removed) and some of them possibly permanent (e.g. probes in the fabric, in the case of forensic investigations).
- Data will be gathered on people's homes, on the feedback they provide, and how they occupy the homes. This has privacy implications, including under GDPR. How this data is presented (e.g. pictures which are anonymised, rather than allowing the identification of the home), stored and who has access to it should be carefully considered with GDPR in mind.
- In addition, the exercise will lead the BPE team to draw conclusions or assumptions (correctly or not) about a wide range of lifestyle and behavioural patterns; they may be influenced by this in how they liaise with inhabitants and how they interpret other findings; they will present their findings to range of audiences; they may in the future, directly or not, use them in other contexts. All of this has ethical implications, which inhabitants must understand before entering into the BPE exercise, and which the BPE team must consider and approach with professionalism in return for the incredibly valuable access and information which inhabitants will provide.

Universities usually have robust ethical processes, which should ensure this will be considered when BPE is carried out by, or with the support of, academics. However, this will often not be the case if BPE becomes a much more common and integrated part of project delivery, and practitioners must therefore become more familiar with these issues too.

INTRODUCTION

The following principles recommended by Fionn Stevenson in Housing Fit for Purpose, 2019 are a useful framework for the BPE team:

- No purposeful harm
- Honestly and integrity
- No coercion
- Informed consent, including a right to withdraw
- A requirement to confidentiality
- Equality and diversity
- Data protection. This should at a very minimum meet requirements set out by General Data Protection Regulations (GDPR) including that only the necessary data should be collected and stored, with a specified and explicit purpose, and treated fairly, lawfully and transparently.

The UK Research Integrity Office provides a checklist for research teams (in any research field), which can be used by BPE teams when scoping out their BPE exercise and identifying potential ethical implications: UK-RIO Recommended Checklist for Researchers, available from ***here.***

1.5 EXISTING BUILDINGS AND RETROFIT

This guidance is primarily aimed for use in new homes. Much of the guidance on individual techniques will remain the same if applied to existing buildings. Some BPE techniques may even be more accurate when used on existing (older) buildings, because the error on the property being measured is similar, but the absolute value is higher (e.g. air leakage, heat loss coefficient).

However there will be important differences in the context for the overall BPE exercise, and therefore the interpretation and action following the results:

- Diagnosing the cause of a problem and possible remediation measures
- Understanding a home's current performance, before any intervention; this should involve a detailed site survey and performance analysis, and gathering and analysing feedback from inhabitants about the current stage of the home.

These aspects are not covered in this guidance.

1.6 PERFORMANCE CONSIDERATIONS SPECIFIC TO TIMBER BUILDINGS

A specific aspect of timber construction which may affect operational performance is moisture:

- Condensation and high moisture contents can lead to degradation, rot, and ultimately structural failure
- Fluctuations in moisture content over the seasons can lead to "movement", which may affect airtightness.

Both can be addressed through careful design, and guidance is provided in relevant sections of this guidance.

Certain types of timber products may also lead to the release of volatile organic content materials, which could affect indoor air quality – see > section 5.3 on ***Indoor Environmental Quality testing and monitoring***.

Less tangibly but no less importantly, timber construction (especially when it is visible, such as cladding or exposed beams) will contribute to the home's appearance and people's perceptions of the home: for some people it could imply, for example, green credentials, or a connection to nature – see more in > section 4.13 on ***user feedback***.

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1.7 References and additional Information

Building Performance Network, authored by Gupta R. and Gregg M., State of the Nation review: Performance evaluation in housing, 2020 https://building-performance.network/research/state-of-the- nation-domestic-buildings

CIBSE, TM61-64 set, Operational Performance, 2020

Gupta R., Gregg M., Cherian R., Developing a new framework to bring consistency and flexibility in evaluating actual building performance, International Journal of Building Pathology and Adaptation, 2019

RIBA, Post Occupancy Evaluation Guidance, webpage
https://www.architecture.com/knowledge-and-resources/resources-landing-page/post-occupancy-evaluation

Stevenson F., Housing Fit for Purpose, 2019 (RIBA Publishing)

Technology Strategy Board, Domestic Building Performance Evaluation, 2016
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/497758/Domestic_Building_Performance_full_report_2016.pdf

SECTION

02

WHAT ARE WE TRYING TO ACHIEVE? SETTING PERFORMANCE OBJECTIVES

Photo by Tatiana Syrikova from Pexels

WHAT ARE WE TRYING TO ACHIEVE?

2.1 OVERVIEW

Setting performance targets for a scheme is an important step. Going above and beyond the base level required by regulation states intentions towards build quality, recognising the climate emergency, enabling health, comfortable and satisfied inhabitants etc.

It is vital that performance objectives are agreed early in the design process and are communicated effectively throughout the build program, including how they are to be checked in use.

Holistic consideration of operational building performance means there should be objectives related to:

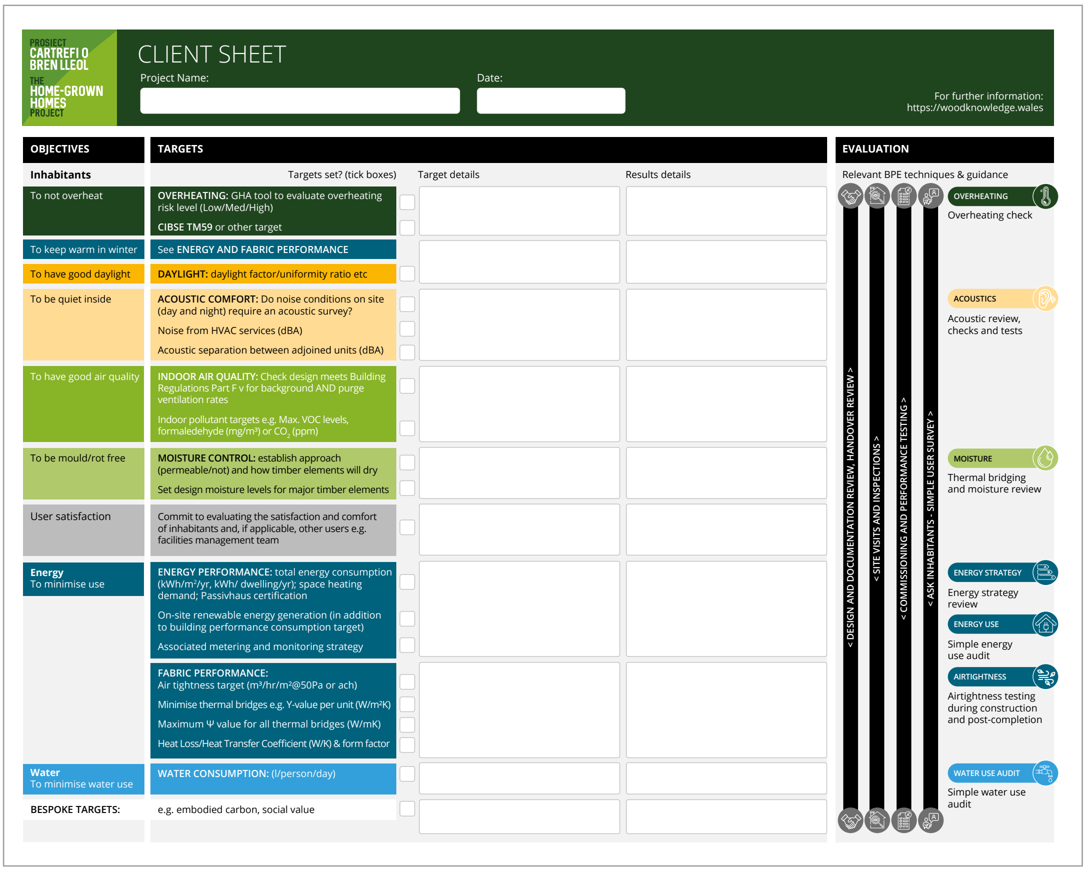
- People: comfort and satisfaction
- Energy use (+ possibly carbon)
- Water consumption
- Indoor environmental quality (IEQ).

Fabric is central to all of these, so teams may wish to set dedicated objectives for this too.

Setting realistic but challenging targets is easier said than done, but focusing early on what outcomes a project intends to meet sends a powerful message and initiates a helpful trajectory. Agreeing and recording the performance targets for a project early on in the design process will help inform the BPE journey, and help focus all stakeholders on the outcomes sought.

In addition, an important aspect of the BPE feedback loop is evaluating outcomes against the original objective to see whether targets may have been set too high or too low: this could be useful reference for future projects; it can also help assess what may be a reasonable deviation from the target due to known factors.

A client sheet has been produced to accompany this guidance, which can be used to record performance objectives and identify how they may be checked as the project progresses – see > ***Client sheet*** in the tool pack. A snapshot view of the client sheet, and examples of objectives against this client sheet are provided below.



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THE HOME-GROWN HOMES PROJECT

CLIENT SHEET

Project Name:

Date:

For further information: https://woodknowledge.wales

OBJECTIVES	TARGETS (Targets set? (tick boxes))	Target details	Results details
Inhabitants			
To not overheat	**OVERHEATING:** GHA tool to evaluate overheating risk level (Low/Med/High) **CIBSE TM59** or other target		
To keep warm in winter	See **ENERGY AND FABRIC PERFORMANCE**		
To have good daylight	**DAYLIGHT:** daylight factor/uniformity ratio etc		
To be quiet inside	**ACOUSTIC COMFORT:** Do noise conditions on site (day and night) require an acoustic survey? Noise from HVAC services (dBA) Acoustic separation between adjoined units (dBA)		
To have good air quality	**INDOOR AIR QUALITY:** Check design meets Building Regulations Part F v for background AND purge ventilation rates Indoor pollutant targets e.g. Max. VOC levels, formaledehyde (mg/m³) or CO_2 (ppm)		
To be mould/rot free	**MOISTURE CONTROL:** establish approach (permeable/not) and how timber elements will dry Set design moisture levels for major timber elements		
User satisfaction	Commit to evaluating the satisfaction and comfort of inhabitants and, if applicable, other users e.g. facilities management team		
Energy To minimise use	**ENERGY PERFORMANCE:** total energy consumption (kWh/m²/yr, kWh/ dwelling/yr); space heating demand; Passivhaus certification On-site renewable energy generation (in addition to building performance consumption target) Associated metering and monitoring strategy		
	FABRIC PERFORMANCE: Air tightness target (m³/hr/m²@50Pa or ach) Minimise thermal bridges e.g. Y-value per unit (W/m²K) Maximum Ψ value for all thermal bridges (W/mK) Heat Loss/Heat Transfer Coefficient (W/K) & form factor		
Water To minimise water use	**WATER CONSUMPTION:** (l/person/day)		
BESPOKE TARGETS:	e.g. embodied carbon, social value		

EVALUATION

Relevant BPE techniques & guidance

< DESIGN AND DOCUMENTATION REVIEW, HANDOVER REVIEW >
< SITE VISITS AND INSPECTIONS >
< COMMISSIONING AND PERFORMANCE TESTING >
< ASK INHABITANTS - SIMPLE USER SURVEY >

OVERHEATING: Overheating check
ACOUSTICS: Acoustic review, checks and tests
MOISTURE: Thermal bridging and moisture review
ENERGY STRATEGY: Energy strategy review
ENERGY USE: Simple energy use audit
AIRTIGHTNESS: Airtightness testing during construction and post-completion
WATER USE AUDIT: Simple water use audit

Client sheet helping teams to set performance objectives: *snapshot view - see > tool pack:* ***Client sheet*** *for the original*

WHAT ARE WE TRYING TO ACHIEVE?

TARGETS Target Set?	**RIBA Challenge 2030**	**HGH Zero Carbon Home** (Jan 2021 draft)	**Passivhaus** Certification
OVERHEATING: GHA tool to evaluate overheating risk level (Low/Med/High) CIBSE TM59 or other target	25-28 °C maximum for 1% of occupied hours; ref to CIBSE TM59	n/a	Max 10% hours over 25°C (dwelling average, not room; steady-state test)
See **ENERGY AND FABRIC PERFORMANCE** **DAYLIGHT:** daylight factor/uniformity ratio etc.	> 2% av. daylight factor, 0.4 uniformity; ref to LG10	n/a	n/a
ACOUSTIC COMFORT: Do noise conditions on site (day and night) require an acoustic survey? Noise from HVAC services (dBA) Acoustic separation between adjoined units (dBA)	n/a	n/a	Max noise from ventilation systems in occupied rooms: ≤ 25 dBA
INDOOR AIR QUALITY: Check design meets BR Part F ventilation rates for background AND purge rates Max. VOC levels, formaldehyde (mg/m³) or CO_2 (ppm)	CO_2 < 900ppm; TVOC < 0.3mg/m³; formaldehyde < 0.1mg/m³; ref to CIBSE TM40	No specific targets, but preference for natural materials, which are often low emission – see "others"	% of hours in a given year with absolute indoor humidity above 12 g/kg: Without active cooling: ≤ 20% With active cooling: ≤ 10 % RH should not be lower than 30% for more than one month.
MOISTURE CONTROL: establish approach (permeable/not) and how timber elements will dry Set design moisture levels for major timber elements	n/a	Vapour permeable materials	Minimum temperature of internal surfaces, and detailing to avoid excessive moisture build up
USER SATISFACTION	carry out post-occupancy evaluation	carry out post-occupancy evaluation	controllability criteria e.g. lighting, heating and ventilation controls, openable windows
ENERGY PERFORMANCE: total energy consumption (kWh/m²/yr, kWh/ dwelling/yr); space heating demand; Passivhaus certification On-site renewable energy generation (in addition to building performance consumption target) Associated metering and monitoring strategy	< 0 to 35 kWh/m²/yr (incl. contribution from on-site renewables)	Space Heating demand < 15 kWh/m²/yr Total Energy Use Intensity < 35 kWh/m²/yr	Total primary energy demand < 120kWh/m² Space heating demand < 15 kWh/m² Space cooling demand < 15 kWh/m²
FABRIC PERFORMANCE: Air tightness target (m³/hr/m²@50Pa or ach) Minimise thermal bridges e.g. Y-value per unit (W/m²K) Maximum Ψ value for all thermal bridges (W/mK) Heat Loss/Heat Transfer Coefficient (W/K) & form factor	"fabric first", but no set target	< 0.6 ach at 50Pa "Thermal bridge free": Ψ < 0.01W/mK U-values for walls, floors, roofs, and complete windows; glazing g-value; building form, orientation and glazing proportion of the facade	< 0.6 ach at 50Pa
WATER CONSUMPTION: (l/person/day)	< 75l/p/day	n/a	n/a
BESPOKE TARGETS: e.g. embodied carbon, social value	Embodied carbon < 300 kgCO_2e/m² (RICS A-C)	Targets for upfront and embodied carbon. Low environmental impact of materials (timber, natural or recycled based products); minimise use of petrochemical-based products	

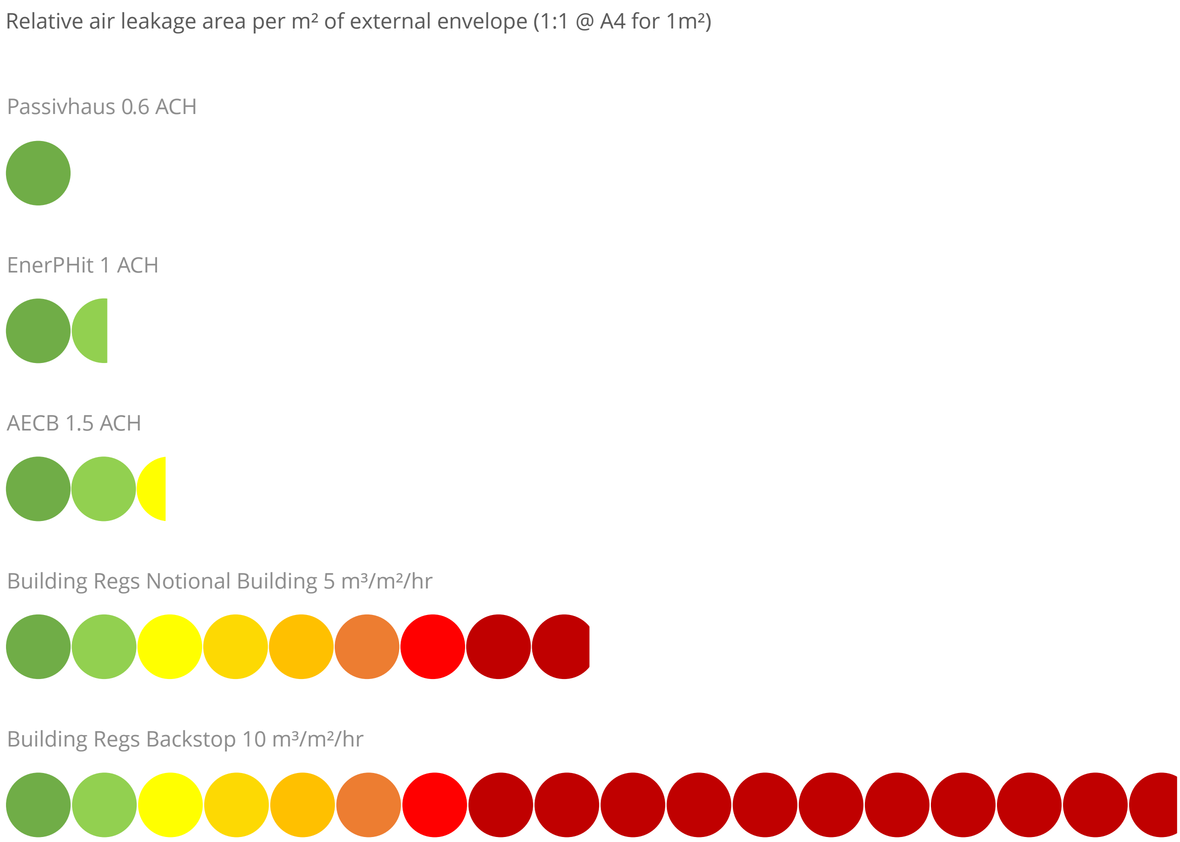
Examples of performance objectives in existing schemes (RIBA 2030, Home Grown Homes – draft, Passivhaus), illustrated against the client sheet

WHAT ARE WE TRYING TO ACHIEVE?

2.2 AIRTIGHTNESS – A CRUCIAL INDICATOR

Airtightness is an important factor for energy efficiency and air quality, but it is often also used as indicator of build quality more generally, as achieving high levels of air tightness requires attention to detail throughout the design and construction.

Significant improvements can be achieved compared to minimum regulatory requirements.



(Source: Passivhaus Trust, Good practice guide to airtightness, 2020)

WHAT ARE WE TRYING TO ACHIEVE?

2.3 USER INVOLVEMENT, COMFORT AND SATISFACTION

It would not be reasonable to set targets for user comfort and satisfaction. However, there should be a commitment to:

- Engage users in the process, from early briefing stages and throughout
- Take their feedback into account
- Incorporate best practice principles, including past BPE lessons, on what tends to lead to good levels of usability, satisfaction and comfort
- Seek their feedback, ideally both through formal surveys and more informal visits and interviews
- Analyse the results carefully, identify areas which seem problematic and seek options for improvements.

Where future residents and other users are not yet known, the project team should seek other ways e.g. via as a very minimum via the identification of common BPE lessons on housing schemes.

If users already involved, the team should early on seek their input on objectives for the scheme. Make sure objectives are relatable, and that implications are understood; if users "buy" into objectives which put them and environmental performance at their heart, this could help retain performance objectives throughout a project.

2.4 LEARNING FROM PREVIOUS BPE

Identify BPE lessons which will need to be taken into account – some are general (e.g. beware of complex systems, favour a fabric first approach), others will emerge as the design project about particular systems or design approaches.

At each stage of the project, identify lessons for future projects (or for later phases, in a large scheme). These lessons could cover design, procurement, construction method, BPE methods, and whether or not the original objectives were appropriate.

WHAT TO DO: OVERVIEW OF BPE ACTIONS AT EACH STAGE, AND WHAT TO DO WITH THE BPE RESULTS

SECTION 03

WHAT TO DO

The team should produce a plan for BPE activities and map them onto the programme. A > ***Project timeline*** of BPE activities at each stage is provided in the Tool Pack.

Home Grown Homes - Illustration of programming BPE activities at the post-occupancy stage: user feedback surveys – Note the careful planning before feedback surveys are sent to residents, including: planning the research strategy, ethical approval, and organising access (*courtesy of Diana Waldron*). At the earlier stages, a less detailed but more encompassing programme should be developed to identify all planned BPE activities, and when they will take place, within the overall design, construction, and handover programme.

Activity + Case Studies	Current Status	Oct 19-23rd	Oct 26-30th	Nov 2-6th	Nov 9-13th	Nov 16-20th	Nov 23-27th	Nov/Dec 30/-4th	Dec 7-11	Dec 14-18th	End of Dec
Develop Research strategy/documents/etc	✓										
CMU Survey Ethical approval	✓										
Housing Association Survey access	✓										
BUS Methodology finalised		C. to update									
Signed agreement with Arup	✓										
Welsh Translation issues		H. to update									
GDPR and Privacy Policy issues		C. to update	C. to update								
BUS Training material to be sent by Arup		H. to update	C. to update								
Zoom meeting with Mid-Wales Housing				D. to update	BUS survey delays due to GDPR issues.		•				
Online survey to be sent to participants					CMU moving to		•				
Progress Report for the Final (Preliminary POE) Report					plan B as stage 1: University			•			
Preliminary Report Submission					developed survey				•		

The programming should pay particular attention to BPE activities which are heavily dependent on sequencing (e.g. inspections which must happen before something is covered) or timing (e.g. those which require a certain difference between inside and outside temperature, which are typically easier to carry out in winter and need heating to be operational, or temporary heating provision). More information on the timing implications of each technique is provided in the one-pager and guidance chapter for each technique.

3.1 DESIGN

For details of activities at this stage, see > Project Stage ***Prompt Sheet - Design***. The aim at this stage is to ensure the performance objectives are clear and integrated into the design, specifications, and procurement. Plans for the handover period and for future BPE (in construction and in-use) should also be established.

3.2 IN CONSTRUCTION

The aim is to ensure the performance objectives and design intent are implemented on site. In addition to formal tests at completion, there are significant opportunities for informal BPE checks throughout, which can often be carried out by the site team provided some training. Empowering the site team to embed performance in their work, so they can carry regular checks themselves and gradually build skills and experience e.g. site induction, toolbox talks, training will often improve overall build quality as well as future performance.

For details of activities at this stage, see > Project Stage ***Prompt Sheet – Construction***.

WHAT TO DO

3.3 COMPLETION AND HANDOVER

The aim is to ensure the performance objectives are met at the as-built stage, that there are good records of the as-built homes, and that inhabitants and other users are satisfied with the level and content of the information and handover provided to them.

Following completion, a period of settling-in should be allowed, and arrangements put in place to prepare the future in-use BPE.

For details of activities at this stage, see > Project Stage ***Prompt Sheet – Completion and Handover***.

3.4 IN USE

This stage is when actual in-use performance can be evaluated; ideally, in-use BPE activities exclude the first year, when inhabitants are "settling in" and some systems may still be getting fine-tuned. The first year can however be used to put everything is in place for the actual in-use BPE.

For details of activities at this stage, see > Project Stage ***Prompt Sheet – In Use***.

3.5 MAKING SENSE OF IT ALL: GAINING A HOLISTIC VIEW ON BUILDING PERFORMANCE

In addition to the value provided by each individual BPE technique, there is huge value in correlating results between techniques when analysing overall performance and trying to identify possible causes and solutions; inhabitants should be involved wherever possible.

Conclusions based on a single BPE technique should be avoided: typically, there should be several BPE activities which together pinpoint the problem and its likely causes.

In very large majority, all core BPE techniques can contribute to the evaluation of all aspects of building performance i.e. energy, people, and indoor environmental quality.

In particular, the results from the design review, handover review and commissioning review should always contribute to the evaluation of all aspects of building performance.

See > ***Making Sense of It All*** diagram in the Tool Pack.

For example, the following techniques contribute well together to the examination of common issues with the performance of homes:

- Energy performance (heating): Airtightness test, thermography spot checks, commissioning of heating systems alongside the energy audit, design review, energy strategy review; heat transfer coefficient measurement.
- Air quality: User surveys on noise (from outside and from ventilation systems), and perceived quality, commissioning of ventilation systems, site observations on ventilation systems, perceived IEQ, and any signs of mould or condensation; humidity and CO_2 spot checks or monitoring (if available), design review – air quality, handover information on the operation of openings and ventilation systems for air quality and humidity management
- Overheating: User surveys, site observations on glazed areas, shading, and their operation, temperature spot checks or short-term monitoring (if available), initial overheating risk analysis, design review – overheating
- Ease of systems: user surveys, site observations, and possibly temperature or air quality spot checks indicating systems not being operated as they should.

All core BPE techniques can contribute to the **evaluation of energy performance**, either by directly relating to the performance of fabrics and systems, or by providing indications of how operation and user behaviour could affect performance.

Even the acoustics and IEQ tests could on occasion contribute to the analysis of energy performance, for example:

- poor acoustic results could be linked to poor installation, which could increase energy consumption or, inversely, lead occupants to reduce the operation of mechanical systems.
- regular and excessive CO_2 levels could indicate mechanical ventilation systems which do not operate properly, possibly with implications on energy consumption too.

WHAT TO DO

Most BPE techniques can contribute to the **evaluation of user feedback** (from residents as well as the management and maintenance teams), either through direct user feedback, or by showing signs of performance, operations and behaviour which could indicate (dis) satisfaction.

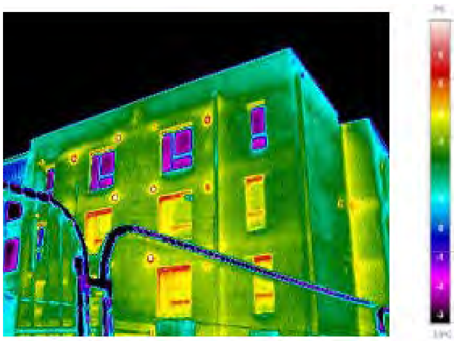
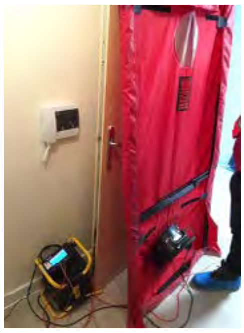
For example, site visits could help spot user interventions such as doors left permanently open to improve cross-flow ventilation, indicating dissatisfaction with indoor air or temperature; or retrofitted elements against solar gains or glare; or ventilation systems which have been turned off, indicating potential dissatisfaction with energy running costs and/or noise.

Most BPE techniques can contribute to the **evaluation of IEQ performance**, either by directly relating to the performance of fabrics and systems and how they could impact the indoor environment, or through direct user feedback on IEQ, or by providing indications of how operation and user behaviour could affect performance.

Even the water audit could provide clues, for example if it showed really high water consumption, which could be linked to high humidity levels and, over time, mould growth.

Additional guidance on how to interpret the results from each BPE technique, individually and alongside other BPE techniques, is provided in the guidance chapter for each technique.

Home Grown Homes – Penton Close: Illustration of how BPE techniques can work together: combining results from co-heating, airtightness, and U-value measurements. In addition, qualitative observations were made with thermal imaging. (*Source: courtesy of Diana Waldron; measurements carried out by Build Test Solutions and SOAP Retrofit)*)


	Flat 4, Ground Floor		Flat 18, Top Floor	
	Design/SAP	Measured	Design/SAP	Measured
Total HTC (W/K)	46	44±6	49	33±5
Heat Loss Parameter (W/m²K)	1.05	1.00	0.89	0.81
Infiltration heat loss (W/K)	8.3	8.5	8.3	10.2
Fabric heat loss (W/K)	38.1	35.8	31.9	23.3

Additional guidance on how to interpret the results from each BPE technique, individually and alongside other BPE techniques, is provided in the guidance chapter for each technique.

WHAT TO DO

3.6 REPORTING ON THE BPE EXERCISE

Reporting on BPE should:

- Be written in non-specialist language, to be understandable to all, including residents
- State which BPE activities were carried out
- Summarise findings from the BPE activities individually and as a whole, considering overall building performance holistically. This should include a comparison with the initial performance objectives (if any were set), regulatory minima and industry best practice, and an indication of whether any departure from the objectives is reasonable or warrants more attention.
- Make recommendations for the next steps, including:
  - Interventions on the building and its operations, if these can be made. Due to the nature of Core BPE, major interventions should generally not be recommended without more detailed investigations, unless the findings from the core BPE are non-equivocal and point to clear needs for intervention and clear causes.
  - Follow-up BPE for more detailed investigation, if applicable. In this case it should be clear why this is recommended and what value in would bring, in order to trigger exercises with a clear purpose, and not to incur additional costs for the sake of it.

SECTION

04

GUIDANCE ON CORE BPE TECHNIQUES

Photo by Lex Photography from Pexels

GUIDANCE ON CORE BPE TECHNIQUES

4.1 TAKING ACCOUNT OF THE EXTERNAL ENVIRONMENT

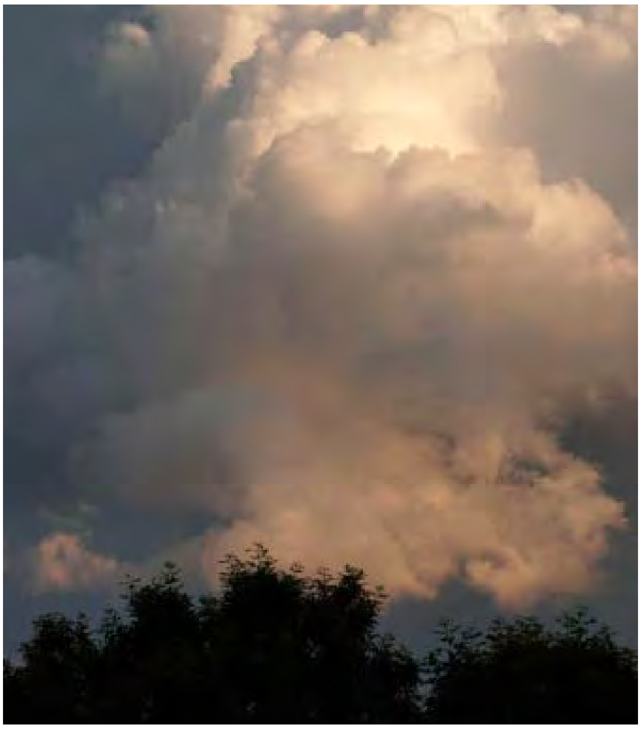
During in-use BPE, data on external conditions will be required to put the data gathered from BPE into context.

Local weather station data is good enough for the core, design stage BPE. For all construction and post occupancy stage BPE activities it is recommended that the specific weather conditions are recorded and considered.

During site visits, the weather that day should be noted (approximately) in terms of temperature, wind speed and direction, whether it rained, and cloud cover (heavily overcast through to bright sunshine).

In addition, the review of user feedback, indoor environmental quality and energy performance should consider the external environment in the time period being studied:

- Winter conditions, when assessing energy consumption and inhabitants' feedback on winter comfort. At its simplest, this can rely on heating degree days for the period examined to get a sense of how cold or mild the winter was.
- Summer conditions, when assessing inhabitants' fee back on summer comfort. This can use local data on temperatures, for example cooling degree days (even if there is no cooling) or temperatures. In the case of complaints of overheating it is useful to look at peaks and durations of high temperatures, both day-time and night-time, as averages may not relate well to people's experience.
- Wind conditions - is the site very exposed, or is it sheltered?



- Air pollution – this could be linked to complaints such as asthma and other respiratory difficulties, or might influence the willingness of inhabitants to open windows for additional ventilation or to reduce overheating.

More specific examples of how to account for this when reviewing the results from individual BPE techniques are provided in the guidance for each technique.

Where more detailed BPE is being undertaken then installation of a weather monitoring station on site may be necessary – see > ***Section 5.1 detailed BPE weather station***.

4.2 DESIGN AND DOCUMENTATION REVIEW

As part of any BPE study, there should be a design and documentation review to understand how objectives, decisions and actions in a project have been recorded and implemented, what documentation has been produced, and whether any verification of the information has taken place.

As for any BPE exercise, the review should seek to check whether lessons from past projects have been incorporated, and identify additional lessons for future schemes.

Ideally, the review should happen at each project stage, as reviews during design development will improve performance, spot issues which would be difficult to rectify later, and ensure that objectives can be verified in use.

Link to > Technique one-pager –
Design and documentation review.

GUIDANCE ON CORE BPE TECHNIQUES

Related BPE techniques: The design and documentation review can typically happen at the same time as:

- Energy strategy review – see ***section 4.5***
- Airtightness review – see ***section 4.8***
- Thermal bridging and moisture review – see ***section 4.6***
- Overheating risk analysis – see ***section 4.4***
- Acoustic review – see ***section 4.10***
- Commissioning review – see **section 4.9**
- Review of handover processes and documentation – see ***section 4.3***

4.2.1 Overview of the technique

The aim of the review should be to identify:

- the building performance objectives set by the team (for example, see > ***Client sheet*** to record these), and how they were communicated among the project team
- how these objectives were integrated in the design and in contractual requirements, including looking at how things work together and any contradictions between design components, and what process of change management was in place to ensure that changes affecting building performance were identified, communicated, and that their consequences were understood
- as-built performance and documentation against the objectives, what checks were carried out, and whether this led to remediation measures
- the changes that have happened which may affect performance, and if possible why they happened (e.g. cost saving, pressure on programme). This can be very helpful during in-use BPE and as lessons for future projects.
- Whether and how users were involved, and how they as well as operational and maintenance implications were considered throughout the design and construction process.

These are fundamental processes and outputs to deliver well-performing buildings. In an ideal world, they should be part of every project, but are often not included or end up compromised by pressures on programmes and budgets. The document review therefore gives a good indication of likely performance: poor documentation, unclear performance objectives and low consideration of end users are high risk indicators of poor in-use performance.

The review also helps analyse findings from the other BPE techniques, and provides a baseline against which to compare findings e.g. how does fabric performance compare with what was specified at tender stage and recorded at the as-built stage?

Basic documentation - The review should examine as a minimum:

- **Outline brief and performance objectives** - see > ***client sheet***
- **Key drawings** for the home, or a typical home in the scheme (e.g. at detailed design and as-built stages: 1:100 or 1:50 site and layout plans, section drawings and elevations); key details such as window openings, foundations and roof junctions but also drawings from a range of disciplines, such as mechanical and electrical
- **Environmental systems, controls and metering strategy**: this is a known weak point of many buildings, as systems often end up too complex for inhabitants and FM teams, and poorly integrated with each other and with the building systems. They include energy, water, ventilation, heating, cooling, lighting, acoustics and biodiversity standards, as well as services specifications.
- **Energy and sustainability strategy**, including objectives, targets, and standards, and approaches relating to climate change mitigation and adaptation, resource use (materials, energy and water), health and wellbeing, pollution (air, water, soil), biodiversity etc.
- **Specific considerations for timber construction**: whether any consideration was given in the design and construction to how timber construction could affect building performance e.g. moisture content, VOC emissions from products, details for airtightness.
- **Handover information and processes:** see > ***section 4.3***. For a prompt of questions and issues to look at, see the > ***Technique one pager*** – Design and Documentation review.

4.2.2 Guidance and application – design stage

The design and documentation could be carried out as part of a wider project stage review, with a focus on building performance, or as a dedicated session. The attendees should ideally include project manager, client, QS, architect, building services engineer, and energy consultant/ modeller. Where present on the team, it can also be really useful to involve the asset/facilities manager and (on private housing) the sales/customer manager, who can bring practical knowledge of what prospective residents are looking for.

The basic documentation (listed in the previous section) should be available, even if only at a very high-level at the early design stages.

GUIDANCE ON CORE BPE TECHNIQUES

The aim of the review is to establish whether design proposals are in line with the building performance objectives, and whether they incorporate past BPE lessons. The review should look at building performance as a whole, including consideration to energy, water, IEQ, and people, with much attention to interactions between disciplines and building elements and to usability e.g. ease of use and maintenance, whether controls are provided and whether they are intuitive and simple enough. It should consider not only the design proposals, but how users have been considered and involved in these proposals.

This should include considerations of maintenance and running cost implications from the design proposals (including the running cost of monitoring equipment, if relevant).

The review should also look at whether the design proposals will facilitate future BPE. Some aspects of BPE, such as IEQ spot-checks and monitoring, may be carried out with temporary equipment used by the BPE team; for others, such as energy and water use analysis, attention at the design stage can greatly facilitate future BPE at little additional cost.

Depending on the scope of the BPE team, outcomes from the review should include the identification of elements that will need resolving and/or detailing in the next stages, and possibly recommended changes for the project team to consider.

It can be really useful to involve residents during the design stage, to explain the proposals, give them an opportunity express their needs and wishes, and comment on the proposals. Typically, this would be best carried out as a separate exercise from the design review itself, focused on the design team.

Illustration of residents involvement at the design stage: Urbed and The Glass-House Community Led Design can support design teams to run activities with residents and actively engage them in the design process. This can involve design workshops, training sessions, study tours etc. A BPE design review identifying that such activities took place would be a very positive sign.

St Raphael's Estate Resident Workshop

Project date	07.09.2019
Type	Consultation Training
Location	Greater London
Clients	The Glasshouse
Associated team members	Helen Berg Marianne Heaslip
Associated documents	

In September 2019, URBED once again teamed up with The Glass-House Community Led Design, to deliver a weekend of collaborative workshops for the residents of St Raphael's Estate in Brent, N. London.

Architects Karakusevic Carson have been commissioned by Brent Council to develop options for the future regeneration of St Raphael's Estate. A significant aspect of the brief was that the design process was to engage and be informed by local residents and stakeholders.

Early within the process, The Glass-House and URBED co-delivered an urban design and 'Homes and Neighbourhood' training course to a mixed group of local residents ('neighbourhood heroes'), alongside Brent Council officers and a representative from the resident board's independent advisor, PPCR.

The course was designed to equip residents with useful urban design skills and knowledge. The training introduced street design principles, opportunities for sustainable design, and tools for reading architectural drawings. Mapping exercises explored the physical, social and environmental qualities of the estate, in relation to basic urban design methods. Participants also undertook an observational tour of Granville New Homes, critiquing successful and unsuccessful qualities of the place, and noting which elements might be appropriate within the context of their own neighbourhood.

Granville New Homes study tour

(Source: http://urbed.coop/projects/st-raphaels-estate-resident-workshop)

GUIDANCE ON CORE BPE TECHNIQUES

4.2.3 Guidance and application – in construction

Construction stage design and document reviews should follow the same principles as the design stage reviews, but with increased level of detail on the construction details, any issues which were previously identified as needing changing, resolving or detailing, any other changes implemented since which could affect building performance, and the handover documentation. Changes from design specifications should be discussed with the team, recorded and, wherever possible, the reasons behind them understood and also recorded.

4.2.4 Guidance and application – completion and handover

Design and document reviews at the completion and handover stage should follow the same principles as the design and construction stage reviews), but using the final as-built documents and focusing on elements which were previously identified as needing changing, resolving or detailing, plus any other change implemented since which could affect building performance. Departures between as-built information, design specifications and performance objectives should be recorded and, wherever possible, the reasons behind understood.

The review should establish whether the as-built documentation is accurate and usable, as it could otherwise make future use, maintenance and BPE much more difficult.

4.2.5 Guidance and application – in use

A design and document review at the in-use stage should follow the same principles as the as-built review, and may not be required in depth if the BPE team already carried out that review at completion. However, it is recommended to carry out a check for anything which may have changed since e.g. things not working anymore, or changed by inhabitants or the FM team. Changes from as-built information should be recorded and, wherever possible, the reasons behind understood; for example, they may indicate residents or other building users made changes to better meet their needs, or because things were not working properly, or they didn't know how to operate them.

What to do with the results?

Correlate with findings from other BPE to assess building performance, identify potential improvements and causes of under-performance, and whether further BPE would be useful - see > Section 3.5 ***"Making sense of it all"*** and > ***illustrative diagram*** in the tool pack.

This BPE exercise is also a good opportunity to complete, modify or update the documentation, if it is found lacking. As BPE will engage inhabitants and other users, these changes should be done in consultation with them, to ensure they meet their needs in terms of format, accessibility and content.

Next BPE steps

The initial design and documentation review, or any other BPE task, may uncover issues which would benefit from a closer look at the design and documentation. This could include:

- **Health and Safety** strategy and standards, including CDM
- More detailed review of **spatial quality and layout strategy**, including storage, adaptability, volumetric quality, and external space, site and layout plans, section drawings and relevant associated information
- **Construction strategy**, including up to the following: construction standards, outline specifications, embodied energy / carbon calculations, construction plans & sections & details, as well as any underlying assumptions / calculations.
- **Maintenance strategy** including whole-life maintenance plan, and CDM standards related to ease of access.

4.2.6 How to make it happen: who to do it, equipment, cost and time implications

A core design and documentation review can be carried out by any design team professional, but they should have some experience of building performance evaluation and ideally independent from the project team.

Professionals with some involvement of community consultation and residents engagement should be involved if the design reviews involve residents.

4.2.7 Regulations

There is no regulatory requirement for a design and documentation review from a building performance perspective (other than basic requirements for commissioning records, CDM and health & safety documentation).

GUIDANCE ON CORE BPE TECHNIQUES

4.3 HANDOVER REVIEW

As part of any BPE study, there should be review of the handover process and documentation, to best meet the needs of the users:

- Throughout the design and construction stage, to check activities and the production of documentation are happening as planned
- At practical completion, to review what has been produced and the activities which have taken plan
- At the in-use stage, to review what has been produced and the activities which have taken plan, what the feedback of the users is about this, and what additional information or support should be provided to improve the building's operation and the users experience.

Link to: > Technique one-pager – ***Handover review***.

4.3.1 Overview of the technique

The aim of the review should be to identify the information provided to the inhabitants and other users (e.g. FM team, building manager) on how homes are meant to perform, and how they should be operated and maintained. This should include information provided in the form of documentation (e.g. Building User Guide) as well as the handover process itself (e.g. site visits, training sessions).

A good handover is fundamental to deliver well-performing buildings. Unfortunately it is often compromised by pressures on programmes, and insufficient consideration of the needs of future users. The handover review therefore gives a good indication of likely performance: a poor handover is a high risk indicator of poor in-use performance.

The review should examine as a minimum:

- **Basic handover documentation:** e.g. production of a Building User Guide for inhabitants and the FM and building management team, whether it was informed by comments from future users and whether it seems to cover key topics in a suitable and clear manner;
- **Handover and induction strategy** plans for site visits and training of inhabitants and FM teams (if any).

Depending on the stage of the project, it should be increasingly clear who will be in charge of these activities and outputs and when, the review and approval processes, and whether a suitable period is identified for it and protected in the programme.

4.3.2 Guidance and application – design stage

At the design stage, the aims of the handover review should be to:

- establish plans for the handover process: what form of support to users will be provided, how they will be involved, when things will happen etc.
- agree the handover information which will be produced: what will be produced (format and content), when, by whom, and how users will be involved.

Reviewing good examples of handover information and processes from other projects can be really useful.

It can be really useful to produce the handover information early, even in outline form, as a way to explain proposals clearly and test the format, content and language with future users.

Users, if they are known, should be given an opportunity to comment on the handover proposals. For example, they may find some examples of documentation difficult to understand of navigate, or they may prefer a "live" training session than relying on web-based or recorded sessions etc.

GUIDANCE ON CORE BPE TECHNIQUES

Illustration of a simple Building User Guide: this does not have to be an extensive document. This one fits on one-page and includes simple instructions to residents on how to operate and maintain systems in their house for energy efficiency, comfort, and health quality.

Project teams may also wish to add other types of information not necessarily related to energy and comfort, for example on cyclist facilities or recycling waste, particularly in schemes where this is centrally managed.

Ranulf Road User Guide

This house is a Passivhaus. The term passivhaus refers to an advanced low energy construction standard for buildings, which have excellent comfort conditions in both winter and summer. They typically achieve a heating saving of 90% compared to existing housing. Passivhaus buildings are easy to live in and require little maintenance, but they do have some important features, which are explained in this guide. The features are simple to operate, but a full understanding will help you get the lowest energy consumption and best comfort. This guide has been design by Alan Clarke and bere:architects for you (the user) to understand how a passivhaus works and how to operate the controls in this house.
Each feature is labelled on the drawings below, highlighting their locations and briefly explaining how to operate them in the corresponding text. Please take the time to read this guide and familiarise yourself with the controls.

Ranulf road south elevation

Ground floor plan

First floor plan

Section A-A

Supply ducts / Extract ducts / Wall construction / Outside air intake

(1) Heat recovery ventilation unit

This unit saves heat from the internal air produced by solar gains, people and electric items to pre-heat a supply of fresh air. If air heating is not required only fresh filtered air is supplied. These filters need to be replaced every 6months in london. The system saves about 10 times more energy than it uses! It is located in the store in an insulated cupboard.

(2) Fresh air vents

The fresh air (pre-warmed in winter) is supplied by the heat recovery unit and delivered to the bedrooms and living room using these fresh air vents. The heating system (10) is automatic but you can adjust the fan speed (4) manually with the wall mounted panel in the dining area. This will keep the air fresh during a party or intensive cooking.

(3) Extract air vents

These vents remove possible stale and damp air from the kitchen, bathroom and utility room. The heat recovery unit saves heat, which saves money. The ventilation runs continuously all year round but special motors have tiny energy consumption. The extract air vent filter need to be cleaned about every 3 months.

(4) Heat recovery ventilation control panel

Min / Normal / Max

The fresh air system can be left on “auto” but the fan speed can also be manually changed using this panel during cooking or if the bathrooms are steamy. If you go away during the winter don’t turn it off but leave it on the lowest speed.

(5) Thermostat

Temp: Up / Down

The thermostat in the living room sets the temperature in the room. 20-21°C is the normal temperature, but you could turn it down if you are away for a few days or just for a few hours to save energy.

(6) Solar tank and boiler control panel

This should be set for all-day-long because the ventilation system is designed to provide gentle continuous heat. It can’t give a quick boost like radiators can. The space heating is controlled with the panel in the dining room (4) and not via this panel.

(7) Towel radiator control

If at any time you wish to run the radiators press the ‘boost’ switch on the wall beside the shower rooms. You can choose half an hour, 1 hour or 2 hours depending on how many times you press the ’boost’ button. The time is indicated by the light display.

(8) Hot water from the sun

In summer almost all the water in the solar tank is heated by the sun shining on the solar panel on the roof. In winter the panel can heat the bottom half of the tank and the boiler is used to top up the temperature. This means there is always hot water available in the tank even on a cloudy day.

(9) Hot water temperature

Hot water is always ready in the tank this is due to the tank being very well insulated so that the water will not cool down overnight. On cold cloudy winter days most of the hot water will be provided by the integrated boiler above the tank .

(10) Heating

A Passivhaus does need a small amount of heating. This comes from the air supply and the towel radiators in the shower room and bathroom. The heat for the towel radiators comes from the gas boiler normally used for hot water. Air heating is automatic but you adjust the temperature on the ventilation control panel (4).

(11) External blinds control (for summer cooling)

In summer the outside blinds minimise solar gains from the sun. These come down automatically in the summer when sunny but can also be manually operated with use of the controller. The controllers have two programs; one blind operation or all together. If it’s too windy outside the blinds will retract to prevent them being damaged. NOTE: A waterproof controller needs to be kept outside to avoid being stuck outside in sunny conditions (11a).

(12) Windows (for summer cooling)

To keep the internal temperature cool in the summer utilse the cooler night temperatures by leaving the windows open in the secure “tilt” position overnight. If it’s hotter outside in the day you can shut the windows and external blinds and then run the heat recovery ventilation on summer by pass to keep cool inside.

bere:architects

For further information regarding these features:

Alan Clarke (Energy Consultant and Building Services Engineer)
Tel: 01594 563356
E-mail: alan@arclarke.co.uk

bere:architects (passivhaus specialists)
Tel: 020 7359 4503
E-mail: bere@bere.co.uk

Delivered with ‘Details for passive Houses’ by IBO Book

(Source: Camden Passivhaus user guide, produced by Bere Architects and Alan Clarke Energy Consultant and Building Services Engineer, and freely available from: here

4.3.3 Guidance and application – in construction

This should follow the same principles as the design stage handover reviews, but with increased level of detail in the documentation, and it should incorporate relevant changes implemented since the design stage.

There should be reasonably complete drafts available towards the end of construction, so that the whole team as well as residents and other future users, especially the Facilities Managers (if any) have an opportunity and suitable time to review them and comment on their accuracy and usability. This should not be left to the final few days / weeks around Practical Completion.

4.3.4 Guidance and application – completion and handover

This should follow the same principles as the design stage handover review, but using the final as-built documents and focusing on elements which were identified as needing changing, resolving or detailing, and any other change implemented since which could affect building performance and usability.

GUIDANCE ON CORE BPE TECHNIQUES

The handover documents (O&M, Building User Guide, training information) should provide simple and clear guidance to occupiers on how to use their systems well. Guidance should be available in a variety of methods suited to occupiers, including images and potentially online information and videos as well as text.

Pay particular attention to whether and how these features are covered, as they may be complex or unfamiliar to residents:

- Ventilation systems: is it clear how the systems work, when they are supposed to operate (e.g. continuously or intermittently on presence / light switch / humidity sensor etc); is the purpose of ventilation made clear, so residents understand it is not advisable to switch them off? If there are several settings, are they explained? If there are filters, is this explained, along with simple guidance on how often and how to change them, and where to buy future filters?
- Heating and (if any) cooling systems and controls.
- Sensors, especially those linked to controls: their location and purpose should be explained, so that residents do not inadvertently remove, move, or cover them.
- Advice on how to mitigate overheating risk e.g. if there is movable shading, is this explained? If the strategy relies on thermal mass, this must be explained: it is often unfamiliar to residents, so they should be advised how to benefit from it with ventilation at cooler (night) times. Openings that can be used safely and securely should also be explained.

Residents and other users should have an opportunity to comment before the final version.

4.3.5 Guidance and application – in use

This should follow the same principles as the as-built handover review, and may not be required in depth if the BPE team already carried out that review at completion. The BPE team should check for discrepancies between the handover information and the actual home e.g. things changed at the late stages of design and construction and not incorporated in the documentation, or changed subsequently by inhabitants or the FM team, or not working anymore. Changes should be recorded and, wherever possible, the reasons behind understood, as they are likely to be a strong indicator of poor performance.

The BPE should also check whether inhabitants and other users (e.g. FM team) are aware of the handover information, what comments they have on it, and whether they find it useful. This may also come up in the user feedback surveys - see > Core BPE - ***User surveys***.

What to do with the results?

Correlate with findings from other BPE techniques, to assess building performance, identify potential improvements and causes of under-performance, and whether further BPE would be useful: see > ***"Making sense of it all"*** in section 3.5.

This BPE exercise is also a good opportunity to complete, modify or update the handover documentation, if they are found lacking, and to recommend additional training sessions or resources if needed. As BPE will engage inhabitants and other users, these recommendations should be done in consultation with them, to ensure they meet their needs in terms of format, accessibility and content.

Next BPE steps

This will depend on whether the core BPE exercise establishes that a particular aspect of the handover process or handover documentation needs to be looked at in more detail e.g. if it was found seriously lacking or inconsistent with as-built information.

4.3.6 How to make it happen: who to do it, equipment, cost and time implications

A core handover review can be carried out by any design team professional, but ideally they should be independent from the project team.

It is important to distinguish the BPE handover review from the formal sign-off process and regulatory checks: BPE has a specific focus and does not replace the formal approval process.

4.3.7 Regulations

There is no regulatory requirement for a handover review itself, but simple documentation must be produced: Building Regulations Part L require that "the owner of the dwelling should be provided with sufficient information about the building, the fixed building services and their maintenance requirements so that the building can be operated in such a manner as to use no more fuel and power than is reasonable in the circumstances".

It is possible that requirements for a simple building user guide will be introduced in future Building Regulations reviews.

GUIDANCE ON CORE BPE TECHNIQUES

4.4 OVERHEATING ANALYSIS – INITIAL ANALYSIS

Overheating in homes has become a significant issue, affecting the comfort and wellbeing of many thousands of people. In the worst cases overheating extends throughout large parts of the year, not just in the warmest months, and the frequency and extent of this are expected to increase with climate change

Link to > ***Technique one-pager – overheating***.

Related BPE techniques:

- Design review – see section 4.2
- Acoustics review – see section 4.10
- User feedback surveys –see section 4.13.

4.4.1 Overview of the technique

Defining how hot is too hot is not straightforward as comfort thresholds and preferences vary from person to person. There are two key tools available for assessing the potential risk of overheating risk in homes during the design stage:

1 **GHA - Overheating in New Homes:** simple reckoner, aimed for use by non-specialists and at the early design stages: recommended as core BPE, described here.
2 **CIBSE TM59 - Design Methodology for the assessment of overheating risk in homes:** more complex and accurate methodology, for use by specialist modellers: – see > ***detailed BPE Overheating analysis*** section 5.10.

SAP Criterion 3 (Appendix P) is a very simple check included within the SAP tool for testing compliance with Part L1A of the Building Regulations. It uses simple assumptions to categorise the overheating risk as either 'high', 'medium', 'slight' or 'low'. This check is not considered to be very robust, so is not covered within this guide.

The Passivhaus calculation methodology PHPP offers an estimate of the overheating risk. Like SAP, it is based on steady-state calculations based on monthly average temperatures, measures overheating against a fixed temperature threshold, and considers risk as an average across the whole dwelling. This can mask localised overheating risk in specific rooms, or at specific times of day, or for periods of a few days such as heatwaves (even if the monthly average is below threshold). Using the Design PH tool to calculate shading via the use of a 3D model of the site can add more accuracy. Overheating risk can be 'stress tested' using PHPP using different scenarios such as future climates or occupancy patterns, a useful function when future residents are not known and to ask robustness to the design. One downside is that it is easy to obtain a predicted risk of zero by simply applying window opening to the model, so it is not considered a very robust overheating check. The tool should ideally only be used to compare the impact of different overheating risk mitigation strategies rather than predict absolute overheating risk, and dynamic thermal modelling tools using CIBSE TM59 are recommended where the overheating risk is significant.

4.4.2 Guidance and application – design stage

It is important to assess overheating risk as early as possible in the design process and definitely pre-planning while changes to the facade can still be made to help mitigate any risk identified. Some planning departments ask for overheating risk assessments as part of planning applications, and this could be the trigger for dynamic modelling – see > ***detailed methodology*** in section 5.10.

GHA - Overheating in New Homes - this is a simple tool developed by the Good Homes Alliance in 2019 to evaluate the risk of overheating at early design stages for new homes. The tool comprises a simple scoresheet (one-page reckoner) with 14 questions (and accompanying guidance notes) which identify and weight the major risk factors that increase the likelihood of overheating occurring, and the factors that may mitigate and help reduce the risk. The tool is designed to identify where developments have a significant overheating risk and give advice on what to do next to reduce the risk to an acceptable limit. The tool is free to download from the GHA website - see references.

At an early design stage, and absolutely before planning, the project team (ideally) or otherwise the BPE team should complete the GHA overheating in new homes one-page reckoner to assess the level of overheating risk. The tool is geared towards assessments of schemes as a whole, but it can also help teams identify individual units likely to score higher: these units should be noted and specific mitigation measures considered.

GUIDANCE ON CORE BPE TECHNIQUES

What to do with the results ?

If the tool predicts a medium or high overheating risk then the team should review elements triggering the higher risk and whether the design can be adapted to mitigate some of this risk.

The largest risk factors for overheating are:

Location - Within the UK - southern counties and inner city locations are more likely to be at risk due to warmer local climate.
Barriers to opening windows - these include external noise, poor air quality/smells, security or safety risks, and adjacency to heat rejection plant.
Glazing ratio - the larger the area of glazing, the more solar heat gains will be admitted to the home, typically a glazing ratio above 35% starts to incur higher risk.
Single aspect - homes with windows on only one side of the building cannot benefit from cross-ventilation
Community heating systems - the hot water pipework operating during the summer leach small but significant amounts of heat that can build up if not effectively dealt with.

The most effective mitigation measures are:

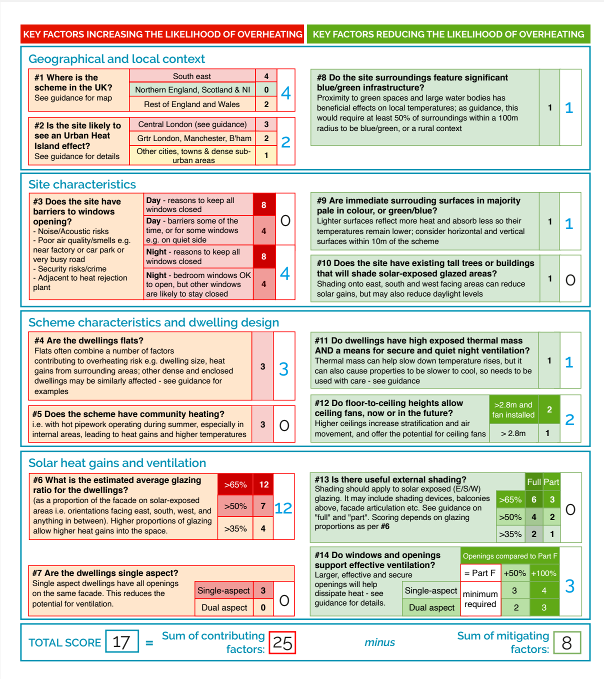
External shading - shutters or awnings etc. that provide shade. This can also include balconies above and other architectural features.
Large, versatile and secure window openings - windows that enable effective ventilation that is easy to operate and can provide secure night time, will maximise the cooling potential.
Higher ceilings increase stratification and offer the potential for ceiling fans to be installed.
Increased thermal mass - thermal mass can be useful but needs to be managed effectively so that heat gains absorbed during the day are effectively purged, otherwise night time temperatures can be increased.
Site features such as large green spaces or bodies of water can provide a cooler micro climate whilst trees or surrounding tall buildings can provide shading. Lighter colours used for paving or cladding will absorb less heat than darker colours keeping site temperatures lower.

If suitable mitigation measures cannot be identified and implemented within the design to reduce the score within the tool then commissioning a dynamic modelling assessment following TM59 is recommended to further explore the risks and suitable mitigation measures – see > ***detailed methodology*** in section 5.10.

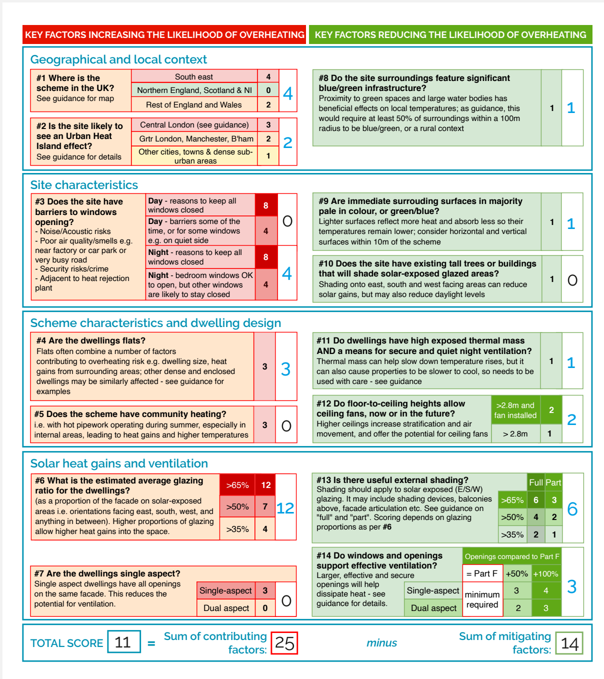
GUIDANCE ON CORE BPE TECHNIQUES

Illustration of GHA tool scoring before and after mitigation options applied

FLAT WITH HIGH PROPORTIONS OF GLAZING - Flat located in outer London



Dual-aspect flat on a relatively green and quiet site with daytime window opening possible in all rooms, and night-time window opening possible in bedrooms (but not in all rooms); the design does not include external shading but includes generous openings and a range of other mitigation measures and no significant other risk factor than glazing proportions.



Same outer London flat, but with **full** external shading on **all** glazed areas:

Total score of 17, high risk: The site location in London and its high proportions of unshaded glazing combine to represent significant risk factors.

Total score of 11, medium risk: This may be fine but does need attention to detail and/or modelling because of the London location and high proportions of glazing.

4.4.3 Guidance and application – in construction

Once the GHA assessment has been carried out, any agreed mitigation measures should be included in the detailed design. It is wise to review the assessment at key points to check that design changes won't have unintended consequences impacting on the overheating risk. Typically this would include changes to the design or specifications, such as the design of shading devices, the location or size of glazed areas, a change to glazing specifications (e.g. a desire to increase light transmittance may mean a lower solar protection factor, or g-value), but other factors may change too e.g. a neighbouring existing building may be demolished and not provide the shading initially assumed.

4.4.4 Guidance and application – completion and handover

Refer to section > ***4.3 Handover review*** to make sure overheating mitigation is covered in the handover process and documentation, including Building User Guide.

4.4.5 Guidance and application – in use

The GHA tool is aimed at the early design stage, however teams may find it useful as a quick sense check at the in-use review, if initial observations or user feedback indicate there may be an issue with overheating. This could only be a qualitative assessment however, to hint at some causes (e.g. reduced capacity for ventilation), and would not capture detailed design issues nor issues related to patterns of occupancy and behaviour (other than those related to window opening behaviour related to factors such as safety, security, or noise).

4.4.6 How to make it happen: who to do it, equipment, cost and time implications

The GHA tool is free to download and was designed to be quick and simple enough for non-specialists to use. It is a good place to start as if the tool predicts a low level of risk, no further action may be required.

4.4.7 Regulatory requirements

The government have published research into overheating in new homes (see references), and it is anticipated that some new form of domestic overheating check may be consulted on soon.

The GHA tool is referenced in the draft Greater London Authority energy assessment guidance for planning applications.

4.4.8 References and Further Information

GHA overheating tool: https://goodhomes.org.uk/overheating-in-new-homes

MHCLG research into overheating in new homes:
www.gov.uk/government/publications/research-into-overheating-in-new-homes

GUIDANCE ON CORE BPE TECHNIQUES

4.5 ENERGY STRATEGY REVIEW

It is necessary to have some understanding of the energy performance of homes being designed, to be able to meet minimum standards and strive for enhanced performance. This will be affected by the approach to building form, fabric, services and appliances. Best results are achieved when all factors are optimised.

Link to > Technique one-pager – ***Energy Strategy Review***.

Related BPE techniques:

- Design and documentation review – see ***section 4.2***
- Airtightness review and testing – see ***section 4.8***
- Thermal bridging and moisture review – see ***section 4.6***
- Overheating risk analysis – see ***section 4.4***
- Site visits (in construction and at the in-use stage) – see ***section 4.7***
- Energy use audit – see ***section 4.11*** (at the in-use stage)
- Review of handover processes and documentation – see ***section 4.3***
- Detailed – thermal bridge analysis – see ***section 5.5***
- Detailed – Energy monitoring and analysis – see ***section 5.7***
- Detailed – Energy modelling – see ***section 5.8***

4.5.1 Overview of the technique

As a very minimum, all projects should include SAP calculations (for Building Regulations purposes, see more details in > ***Definitions*** in section 7.1). A review of the design from an energy perspective should also be carried out to check that:

- best practice principles are followed in the design of the building form, fabric performance, and services (ventilation, lighting, heating and hot water, cooling if any)
- SAP calculations are carried out properly, and they are appropriate for the project performance objectives, otherwise more detailed calculations are recommended – see Detailed BPE > ***energy modelling*** in section 5.8.
- The metering and monitoring strategy is in line with best practice for inhabitants and other users, and to facilitate future BPE.

4.5.2 Guidance and application – design stage

The energy strategy review should be carried out at the design stage, to inform proposals and assess options. Energy calculations usually need to be revisited several times to ensure that targets continue to be met as the design evolves. Very early stage calculations might only cover one or two sample units to explore the impact of early decisions such as orientation and form factors, with more units included as the design settles.

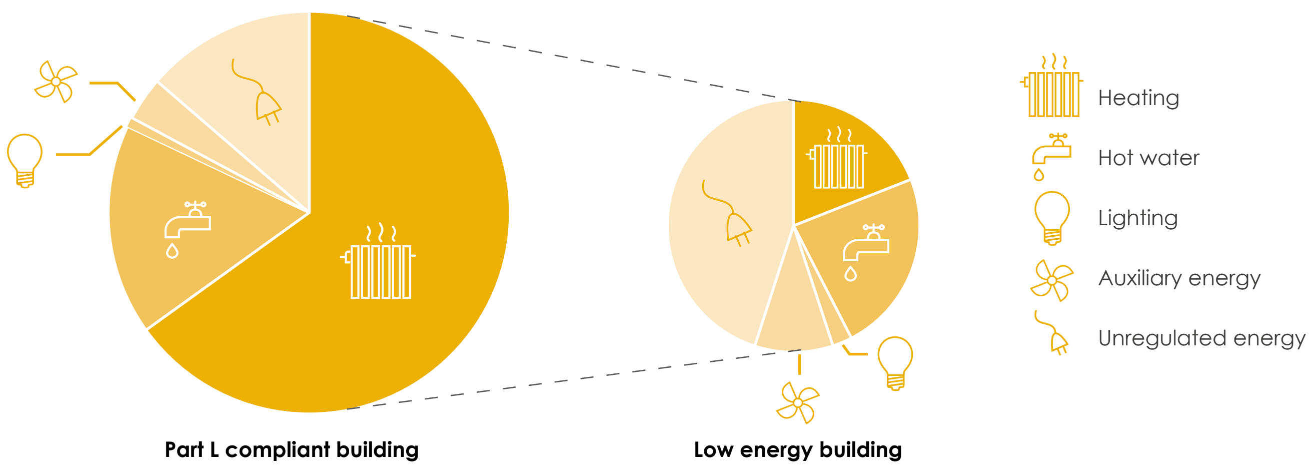


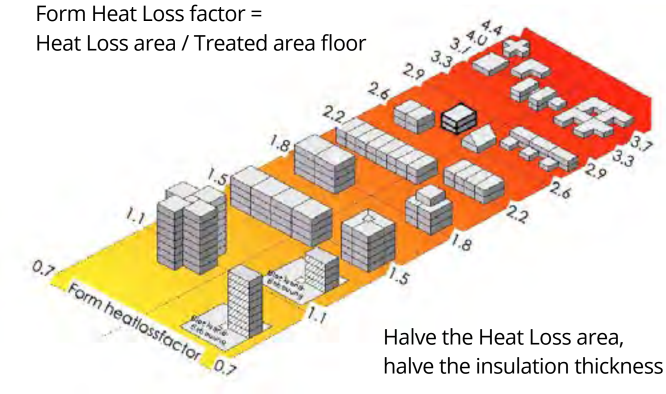
Illustration of residential energy breakdown, comparing a low energy building against one that would just meet regulatory compliance (source: LETI)

GUIDANCE ON CORE BPE TECHNIQUES

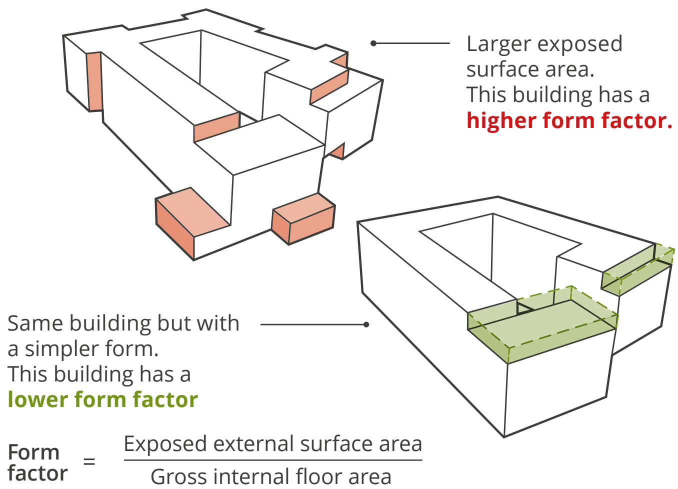
The review of the energy strategy should include:

- Passive design principles including orientation, building form and layout, glazing location, amount, and shading
- Approach to fabric performance including designing for air tightness - see core BPE, ***U-values and thermal bridging***
- Ventilation: if mechanical (recommended in airtight homes), check whether it is Mechanical Ventilation with Heat Recovery (MVHR); what are the intended specific fan power and heat recovery efficiency, and the duct types and routes? Are bends and length minimised? A wider check on the proposed performance of the ventilation systems should be carried out at the same time, including: air flow rate, filtration requirements, noise levels – see > core BPE ***Acoustic review***, level and type of control. Does the heat recovery have an effective summer bypass? For best practice on MVHR in individual dwellings, refer to Passivhaus Trust Good practice guide to MVHR for single dwellings - see references
- Performance of space heating and hot water system, including efficiency (full and part load e.g. COP curve if heat pump), level and type of control, air polluting emissions (if biomass and fossil-fuel based), biomass fuel specifications (e.g. sourcing, moisture content) if applicable
- SAP calculations: high-level review of results, inputs, and consistency with design documentation; is SAP is appropriate to the objectives, or are more detailed calculations required e.g. it should be PHPP if the target is Passivhaus – see detailed BPE > ***Energy Modelling in section 5.8.*** If only SAP calculations are available, the limitations of SAP as an energy prediction and design tool should be explained to the client, as it is not intended for this but for regulatory compliance and asset ratings.
- Thermal bridging – what is unit Y-value and could it be improved? – see core BPE > ***thermal bridging and moisture review*** in section 4.6
- Metering and monitoring strategy: Will it facilitate engagement of inhabitants with their energy consumption? Will it facilitate in-use BPE? Is there sub-metering for complex plant items and on-site renewables, and to separate electricity consumption for space heating and hot water if the home is all-electric? See more prompts below.

Illustrations of issue to be looked at in an energy strategy review, at the early design stages: Form factor



Source: Passivhaus institut



Source: www.levittbernstein.co.uk/site/assets/files/3553/passivhaus-easi-guide_screen_portrait.pdf

The form factor of a building, or how compact it is (i.e. the amount of envelope area compared to its floor area), will influence its space heating demand.

Check the energy use predictions are in line with the objectives, and that assumptions seem realistic and in line with the design and specs, the overheating analysis and other applicable elements e.g. thermal bridging analysis. Highlight where assumptions may need further analysis to be verified e.g. thermal bridging analysis may be required if details are not ACD (Approved Construction Details), or if very good values are assumed without back-up evidence.

Depending on the scope of the BPE appointment highlight where there may be opportunities for improvements or where assumptions seem over-optimistic. Best carried out as part of the design review – see > ***section 4.2***

GUIDANCE ON CORE BPE TECHNIQUES

Metering and monitoring considerations

Good metering will help inhabitants and FM teams know what their energy consumption is, which is the first step to improving it.

There should be metering on separate fuel supplies, ideally with logging and remote monitoring capability and easy access for users (this should be the case with smart meters but some arrangements are more straightforward than others). Meters should be MID approved (Measuring Instrument Directive).

While electricity sub-meters are relatively easy to install temporarily for BPE, measuring delivered heat can be much harder and more expensive: in homes delivered by communal heating, some attention at the design stage will greatly facilitate the BPE later on.

Homes are expected to increasingly be all-electric in the future, but it is recommended that the team should discuss the option of separately sub-metering electricity input for heating and hot water, to facilitate BPE; alternatively, the BPE team may install temporary meters on individual circuits at the in-use stage for the duration of the monitoring period.

The inputs and outputs to / from heat pumps, solar thermal panels, solar photovoltaic (PV) panels and other low-carbon and renewable energy systems should be sub-metered, so their contribution to the building demand and their exports to the grid and/or other users can be established.

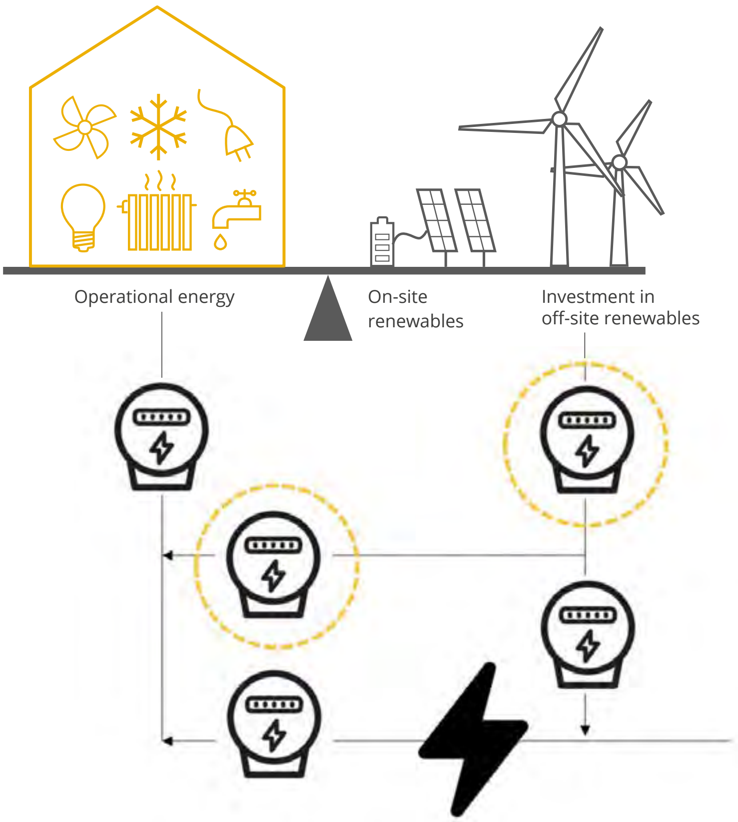


Illustration of metering and on-site supplies:
If homes are served by on-site generation such as solar panels, they should be sub-metered so that their total output and their contribution to the building can be identified: to assess the building's performance itself, it is important to be able to establish what the building demand is, separately from how that demand is met (i.e. from the grid and from other supplies). In the illustration, several arrangements are possible; in theory, both circled meters are not required as one value could be estimated from the other alongside the reading of exported energy to the grid. However, it can be useful to have a way to cross-check meter readings are right, since issues with reliability of data are common (often linked to inadequate commissioning).

The metering strategy should also enable the evaluation of any contribution from on-site storage (e.g. batteries) and, ideally, their efficiencies.

Source: LETI illustration of an operational energy balance, with adaptations to show grid supplies and metering

If the home is served by communal heating, there should as a minimum be heat sub-metering per block; heat meters can be relatively expensive and it may be acceptable not to sub-meter every single dwelling, but the team should in that case agree a reasonable provision (e.g. per riser) and method of apportioning demand for BPE and billing purposes; for accuracy of heat metering it is recommended that heat meters should meet MID Class 3 accuracy standards (or better) and have temperature sensors installed in the fluid flow (using pockets or 'Binder' type points). Metering arrangements for the domestic Renewable Heat Incentive and Feed-In Tariffs are a useful reference of what should be expected as a minimum, and as best practice; a "high specification" package would be the RHI Metering and Monitoring Service Package (MMSP), which includes logging every 2 minutes.

GUIDANCE ON CORE BPE TECHNIQUES

4.5.3 Guidance and application – in construction

Monitor changes to the design and proper installation, as part of the core BPE > ***Design Review*** and core BPE > ***Site inspections***. Highlight whether this changes any of the expected energy performance, and whether some changes to the energy calculations will be required.

4.5.4 Guidance and application – completion and handover

As per construction, checking as-built details.

4.5.5 Guidance and application – in use

As per construction, checking as-built details and comparing with in-use findings. See also core BPE > ***energy audit*** in section 4.11.

4.5.6 How to make it happen: who to do it, equipment, cost and time implications

The energy strategy review can be carried out by the design team – potentially led by the M&E designer / Passivhaus consultant / sustainability consultant, but ideally with the involvement of an independent professional with some experience of BPE. Some engineering and architecture firms do these reviews internally, with the independent eyes provided by the staff not involved in the project.
A review should typically take approximately 0.5-1 day depending on the size and complexity of the scheme, and should be revisited at each RIBA stage until sign off.

4.5.7 Regulatory requirements

At practical completion the final SAP calculations and Energy Performance Certificates must be produced by an accredited assessor for Building Control approval, and so that EPCs can be lodged within the Landmark database and a formal certificate issued. A register of accredited domestic energy assessors is provided by MHCLG here: www.epcregister.com/searchAssessor.html

4.5.8 References and further information

LETI Climate Emergency Design Guide, 2019: This can give prompts during the energy strategy review on design principles for low-energy dwellings

Etude & Levitt Bernstein, Easiguide to Passivhaus, 2020:
www.levittbernstein.co.uk/research-writing/easi-guide-to-passivhaus-design
This can give prompts during the energy strategy review on design principles for Passivhaus and low-energy dwellings

Passivhaus Trust - Good practice guide to MVHR for single dwellings www.passivhaustrust.org.uk/guidance_detail.php?gId=39
This can give prompts during the energy strategy review on design principles for efficient mechanical ventilation with heat recovery systems

GUIDANCE ON CORE BPE TECHNIQUES

4.6 THERMAL BRIDGE AND MOISTURE: DESIGN REVIEW AND SITE CHECKS

Understanding thermal (or cold) bridging is an important aspect of fabric performance. Thermal bridges are not just a location of heat loss, but the resulting colder surfaces are often linked to mould formation. For definitions and how it is used in SAP calculations, see > ***Definitions*** section 7.2.

Link to > Technique one-pager – ***thermal bridging and moisture review***.

Related BPE techniques:
- Energy strategy review – see > ***section 4.6***
- Airtightness review and testing – see > ***section 4.8***
- User feedback surveys – see > ***section 4.13***

4.6.1 Overview of the technique

Reviewing thermal bridges is a good opportunity to assess how details are designed, whether they could be improved and how they will be built including the sequencing. More complex details introduce greater risks both in terms of heat loss and of buildability so complex details should be justifiable. Knowing where they are within a design can also enable extra focus to be given to them construction and post-construction checks.

Alongside thermal bridging, understanding moisture flows will help to avoid surface and interstitial condensation and degradation (rot) if moisture levels are too high over long periods.

As part of the core BPE, designers should follow best practice principles to minimise thermal bridging and limit the risk of condensation. They should also, where possible, use Accredited Construction Details (ACDs) (or other details for which reliable thermal bridging calculations exist) as this limits the need for more complex thermal bridging calculations.

Where an initial review of design proposals and details indicates a potential risk of condensation and/or it is not possible to use details for which thermal bridge calculations already exist, then a more detailed exercise may be required: thermal bridge analysis, or even a hygrothermal (heat and moisture) analysis – see > Detailed BPE ***thermal bridge analysis*** in section 5.5 & Detailed BPE ***hygrothermal analysis*** in section 5.6.

Specific considerations in timber construction

The risk of condensation and high moisture content is particularly important in timber construction as in the long-term it can ultimately lead to rot, fabric degradation, and structural failure.

The key risks of thermal bridging in timber construction are often with the structural elements; the architect and energy modeller should therefore seek early input from the timber frame manufacturer.

4.6.2 Guidance and application – design stage

Thermal bridging happens at changes in the geometry (e.g. corners) and material properties. At its simplest, the principle to avoid thermal bridging is a continuous layer with no significant changes in thermal properties. While this sounds simple, it can be difficult to achieve in practice, particularly when facades are articulated and when details become complex.

The performance specification for a project should specify a target thermal bridging value for the whole home (Y-value) – see > ***client sheet***, filled-in client sheet examples, and an ***overview of targets*** in section 2 .

Designers should think about construction details in 3D, to establish how they will be built on site, including sequencing and giving sufficient tolerances - details can be easier to draw in CAD than they are to construct on a building site. This will also help for achieving good airtightness and general build quality.

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One of the aims of the Passivhaus standard is for the home to be "thermal bridge free", so it is a useful reference for best practice on minimising thermal bridging. The Passivhaus Trust provides the following Rules of Thumb:

The use of external dimensions allows a Passivhaus Certifier to conduct a visual assessment of thermal bridging. If they are satisfied, then thermal bridging calculations may be avoided. A detail may be considered 'thermal bridge free' when the following rules are met:

Prevention: Try to avoid disruptions to the thermal envelope.

Penetration: Where an unavoidable disruption is made to the insulating layer, the thermal resistance in the insulation should be as high as possible.

Junction: At the junction between building elements insulating layers should join without interruption or misalignment.

Complexity: Minimise complexity – this reduces the chance of error and can assist buildability.

Geometry: Design edges and corners to have as obtuse angles as possible. Pay specific attention to corners, ground floor/wall interfaces, eaves, verges, gable ends, structural openings (head, jamb and sill).

Buildability: Ensure that simple robust details are developed with adequate construction tolerance.

Construction tolerance: Think of a reasonable dimension for a construction tolerance, and then double it.

Protection: Protect insulation materials from mechanical damage and the weather.

Workmanship: Avoid gaps and discontinuities and ensure a clean working environment.

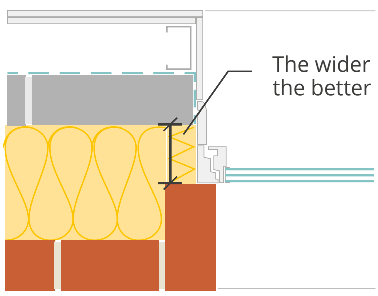
Improvisation: Do not improvise, read the drawings and specification or ask the design team if unclear.

Inspection: Inspect details prior to closing any openings, to ensure that the there are no gaps and discontinuities.

Illustration - Passivhaus Trust Rules of Thumb to minimise thermal bridges

A review of thermal bridging should look at whether the design proposals are likely to introduce significant thermal bridges: this could be a large amount of occurrences (e.g. very articulated façade), and/or particular details which cause a high risk because of discontinuity in insulation or are difficulty to build in practice. Where this is the case, it should look at whether simplifications could be introduced.

Once design principles are checked, individual details should be reviewed. The Zero Carbon Hub Thermal Bridging Guide (2016) provides useful guidance (see references) on the key junctions to 'get right' or improve as some will be larger in scale or have a greater Ψ value and therefore should be prioritised.



Window detail

Position windows so that they are tied back to the inner structural leaf. The frame should mostly sit in the insulation zone to reduce thermal bridging.

The installation details can hide much of the frame to give a slim appearance.

Illustration of issue to look for during a thermal bridging review at the design stage: design detail to reduce thermal bridging around a window (source: Levitt Bernstein & Etude, Easiguide, 2020)

The simplest route is to use Accredited Construction Details (ACDs) as this should ensure reduced thermal bridging and it provides thermal bridging values without the need for calculations. It also allows a Y-value of 0.08W/m²K to be entered into the SAP assessment, although this may change in the upcoming revision of Part L depending on the outcomes of the consultation process – Where the targeted Y-value is lower than this, or suitable ACDs are not available other reliable sources can be looked at - see references, and Home-Grown Homes Work Package 6 for examples. If this still fails to provide relevant calculations, and the team establish that the details cannot be changed, then they will require bespoke calculations, to be carried out by an expert – see detailed BPE> ***thermal bridge analysis*** in section 5.5.

ACDs for **timber frame construction** are available. The details provided are valid for a range of timber frame wall thicknesses from 89mm up to 150mm stud size. The Zero Carbon Hub Thermal Bridging Guide (see references) includes design detail recommendations for timber frame construction.

Alongside thermal bridging, the review should consider **moisture movement** through the fabric: from the inside outwards i.e. moisture generated indoors from occupants, pets and activities such as washing, cooking etc; and from the outside inwards i.e. moisture from outdoor air, rain, and the ground. This requires an understanding of likely temperatures at surfaces and within the build-up, as well as material properties, in order to limit the risk of surface and interstitial condensation. This should be checked throughout (not only at junctions), but thermal bridge points are key risk areas and the thermal bridging review is a good opportunity to look at envelope performance and check moisture movement at the same time.

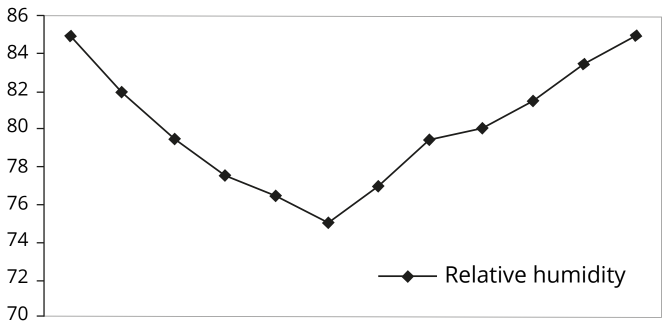
The key principles to check include:

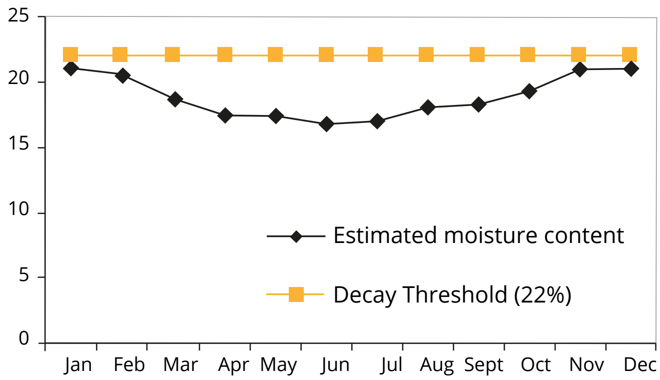
- Have inwards and outwards moisture flows been considered in the design strategy, including selection of materials, air gaps, vapour control strategy (barriers or vapour-permeable materials), wind barriers etc? In timber construction, designing the airtightness layer inside the thermal line helps moisture in the fabric to dry out. Is the approach consistent with the approach to heat flows? Pay particular attention to thermal bridging, where condensation could occur.

- Do the specifications consider moisture content in timber? Recommended ranges and advice on how to specify for moisture content is available from TRADA (Wood Information Sheet 4-14, and additional notes for specific timber applications) – see references. Do the specifications make clear that the site teams should check the moisture content when timber is delivered, and what they should do if the actual content differs from that specified (e.g. period of drying) ?

- Do details allow for timber movement related to seasonal variations? This will also help maintain airtightness.

Illustration of natural variations in moisture content of timber over a year, while staying below the decay threshold





Moisture content and relative humidity
Source: TRADA Learning Resources, Timber as a material - moisture content and durability, 2019

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4.6.3 Guidance and application – in construction

Monitor changes to the design and check the installation. Site visits will be really important to check construction details, the materials being stored and installed etc. for example:

- On cold days (and ideally cloudy days, or early morning / early evening), using thermal imaging (ref > ***thermography*** section 5.2) to identify cold spots – these could indicate either thermal bridging or air leakage (particularly useful during a depressurisation test, but can still be useful anyway); this could be done informally, outside of a full specialist thermography survey. Pay particular attention to details which were identified at the design stage as being complex to build, or a risk of thermal bridging.
- Materials (e.g. timber, insulation) stored without being protected from the rain may get damaged and/or absorb humidity, which could lead to degradation, humidity build up, degradation and mould problems in the future.
- Spot check that the moisture content of timber on delivery and at installation is within recommended levels. This is especially recommended if the storage areas are exposed, and in periods of very wet weather. The TRADA Information Sheet WIS 4-14 provides recommendations for testing and interpreting readings. Check what procedures are in place if the moisture content differs significantly from the specs e.g. drying.
- Are the materials as per specifications? If there have been substitutions, do materials and build-ups remain in line with the approach to moisture flow e.g. breathable if this was part of the strategy?
- Are air gaps, rain membrane and vapour control layers (if specified) in place as per design?

Illustration of moisture strategy checks during the construction stage: Example of 2-pin capacitance moisture meter being used on timber before it is installed; this is a common type of moisture meter for this type of application. (Source: Testo)

Highlight whether any changes to the design or materials may affect the thermal bridging and moisture risk analysis, and whether some changes mean that more detailed analysis will be required (e.g. if an installed detail is not part of ACDs, when it as assumed at the design stage; if a breathable product was changed to an impermeable one; if some timber elements were installed at higher moisture level than specified or typically acceptable (20% would be the typically accepted threshold on average, with no individual reading over 24% (TRADA WIS 4-14, 2019).

4.6.4 Guidance and application – completion and handover

As per construction, checking as-built details.

4.6.5 Guidance and application – in use

A site visit and/or conversation with inhabitants can check for signs of visible condensation and mould growth, but these may take time to develop and would not capture interstitial condensation. Thermal bridging can also be checked using a thermography survey – see > ***Detailed BPE***, but this is only qualitative rather than allowing a direct comparison with the calculated thermal bridges, and would usually not capture all issues.

If problems are observed, some investigation is recommended on the likely causes and possible remediation, starting with a review of thermal bridging and moisture flows based on as-built information. This may lead to more detailed analysis (see > ***detailed BPE***), particularly if thermal bridging and/or condensation is severe and could lead to fabric and structural degradation.

4.6.6 How to make it happen: who to do it, equipment, cost and time implications

The review of thermal bridges and moisture flow does not strictly speaking need a specialist; it could be carried out by an architect, energy modeller, building physicist or Passivhaus designer, however they should be experienced in thermal bridging analysis and have a good understanding of building physics and materials properties.

The TRADA Information Sheet WIS 4-14 provides an overview of instruments and recommendations for testing procedures. Spot checking of moisture levels in timber: the most common type of instrument is capacitance meters (2 or 3 pin). They should be calibrated; the instructions may be provided by the manufacturer or, for example, from BSRIA if the instrument is purchased or hired from them.

4.6.7 Regulatory requirements

Building Regulations Approved Documents C, F and F include provisions to minimise the risk of condensation and thermal bridging (surface and interstitial). In practice they are not necessarily well applied, nor comprehensive enough.

Within SAP - where detailed thermal bridging calculations have been done the predicted total heat loss (Y) is entered into box 36. If calculations are not done then a default Y-value of 0.15 W/m²K is applied, or 0.08W/m²K if Accredited Construction Details (ACDs) have been used. This may change in the upcoming revision of Part L depending on the outcomes of the consultation process.

4.6.8 References and Further Information

Thermal Bridging Guide published by the Zero Carbon Hub (2016)
www.zerocarbonhub.org/sites/default/files/resources/reports/ZCH-ThermalBridgingGuide-Screen_0.pdf

How to Build a Passivhaus - Rules of Thumb www.passivhaustrust.org.uk/UserFiles/File/Technical%20Papers/ROT/How%20to%20build%20a%20Passivhaus_Chapters%201%20to%204(2).pdf

Advanced Details www.advanceddetails.co.uk/ - free libraries of details with thermal bridging values - email sign up required (Toby Cambray)

Passivhaus Easiguide, 2020 (Etude & Levitt Bernstein, endorsed by the Passivhaus Trust)
www.levittbernstein.co.uk/research-writing/easi-guide-to-passivhaus-design/

TRADA Wood Information Sheet WIS 4-14, Moisture in Timber, March 2019 (small fee for download)
http://bookshop.trada.co.uk/bookshop/view/9cf36964-39bc-458e-a7d6-703bc3cd149f

GUIDANCE ON CORE BPE TECHNIQUES

4.7 SITE VISITS AND INSPECTIONS

4.7.1 Overview of the technique

No BPE exercise can be truly valuable without a site visit. This is useful at any stage to understand the site, inspect procedures and progress during construction, and experience directly how the building operates, gathering feedback directly from inhabitants and other users if possible, and helping to make sense of all the other BPE results.

4.7.2 Guidance and application – design stage

If possible, the BPE team may find it useful to visit the site at the design stage accompanied by the project team and, ideally, future inhabitants. This is an opportunity to go through the design proposals, query how they relate to the site and how environmental considerations have been taken into account. It is also an opportunity for the project team and BPE team to explain the proposals to the future inhabitants and gather insights from them about their preferences and how they are likely to use their future homes. In return, it can help these inhabitants to understand certain constraints and how the design intends to respond to these.

4.7.3 Guidance and application – in construction

See > Technique one pager – ***site visit – in construction***.

Site inspections and informal checks with a focus on building performance should be carried out regularly during construction.

A review of the programme before start on site (see ***chapter 3***) should have established when site inspections and checks should be carried out.

Outcomes from the site inspections should be to establish whether design proposals are being implemented in line with best practice, and to make recommendations where improvements are required to the build, to construction details and specifications, or to site procedures (including whether additional training or supervision is required).

A number of issues to look at during site inspections will have been determined during the design review (see > core BPE - ***design review***), for example which construction details are a risk of air leakage and therefore require particular attention. In general, items which benefit from attention from a building performance perspective include:

- Ventilation: inlets not being blocked, ducts clean etc. For mechanical ventilation systems: see > ***Commissioning*** section 4.9
- Items with implications on heat and moisture flows: see > ***chapter 4.6*** and ***technique one pager***
- Airtightness: see > airtightness ***chapter 4.8*** and ***technique*** one-pager, which includes prompts for issues to look at.

4.7.4 Guidance and application – completion and handover

As per "in construction", but based on the as-built stage and as-built BPE results.

4.7.5 Guidance and application – in use

A visit of the building in use is invaluable to experience how homes operate and put all the other BPE results into context. Whenever possible this should be done with the inhabitants, to gather additional feedback and insights directly from them.

Ideally, this would be a thorough walkthrough with the residents where they are invited to actively show the team what is working and what is not, on room by room basis. A home tour guide was produced for the Technology Strategy Board BPE programme. If this is not possible, even a simple walk-around (even, at its extreme, from the outside only) can bring valuable insights, particularly for experienced BPE practitioners.

A list of general prompts during in-use site visits is included in the technique one-pager > Core BPE ***site visit – in use***. In general, items which benefit from attention from a building performance perspective include the following:

- How things work: heating, hot water, ventilation and lighting, and – importantly – their controls: do they seem to work well? Do they seem easy to use? Are systems switched off, when they shouldn't be e.g. continuous extract fans or MVHR? Do they switch on when they should e.g. intermittent extract fans in bathrooms? Is the MVHR unit easy to access? Is it easy to tell when the filter needs changing, and is it easy to access and change it?
- Windows and glazed areas: how well they open, safety and security, interaction with shading devices, consistency with overheating risk strategy – see ***Design review*** in section 4.2 and ***Overheating analysis*** in section 4.4 .
- General impressions on daylight and views
- Any visible signs of mould or condensation?

- Perceived air quality and thermal comfort e.g. stuffy air, overheating, draughts – this should be complemented by questions with inhabitants, if they are present, and potentially by spot checks (temperature, humidity, CO_2), if the BPE team have such instruments – see > ***section 5.3***.
- How do the acoustics seem to be? Does it seem reasonably well insulated from neighbours and outside noise? Is the site noisy?
- Thermography spot checks, if the BPE team have the instruments and if the day is suitable for it (i.e. cold enough outside for a minimum 10°C temperature difference from the inside, and ideally before sunrise / after sunset or when heavily overcast) – see > ***section 5.2.***
- Storage – general (lots of things kept on balconies or sunspaces would be a sign of insufficient storage, particularly if it is repeated across the majority of homes on a scheme); bins and bicycle storage; bins.

In addition, a number of issues to look at during site visits will have been determined during the design review (see > core ***BPE design review***), for example complex systems which are at risk of not being installed properly or being difficult for inhabitants to understand and operate correctly.

Next BPE steps

The initial site visit, alongside the design and documentation review or any other BPE task, may uncover issues which would benefit from more detailed investigations of build quality, for example a full construction audit and full photographic survey. They could cover the whole build, or have a more limited scope to look at the specific issues uncovered more in depth.

4.7.6 How to make it happen: who to do it, equipment, cost and time implications

Site inspections at the design and in use stages may be carried out by any design team professional, but if possible with some BPE experience.

In the core BPE, no equipment is necessary. Some professionals may wish to complement their visits with spot checks such as thermal images (with a thermography camera) or measurements of temperature or other environmental conditions; these may be useful but are not necessary and caution is required as spot checks may not be representative – see spot checks in > detailed BPE - ***thermography*** and ***IEQ chapters*** section 5.2.

Site inspections during construction may be carried out by any design team professional, but they should be independent from the project team and would require substantial experience of construction and of BPE; on many projects it may be that tasks are shared among several individuals, with some carried out by people more specialised in some areas e.g. Passivhaus designers or certifiers to examine thermal bridging and airtightness details. No equipment is required, although some professionals may wish to bring their own e.g. torches to inspect details, smoke pens to spot air leaks, thermal imaging cameras for spot checks.

4.7.7 Regulatory requirements

None

4.8 AIRTIGHTNESS REVIEW AND TESTING

4.8.1 Overview of the technique

Air pressure testing quantifies how "leaky" or "airtight" a building is. It can be useful for several purposes:

- As a general indication of build quality
- To quantify overall airtightness and identify associated sources of air leakage.

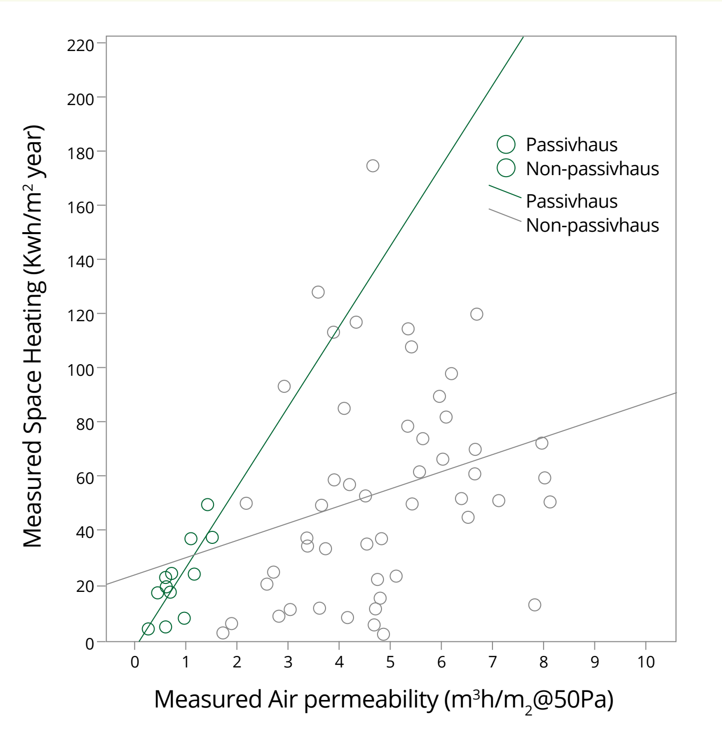
Why does airtightness matter? Heat losses through air leakage can be significant, sometimes higher than those through the fabric elements. In addition, poor airtightness can have implications on thermal comfort (draughts), noise, fabric degradation (condensation, leading to mould over a period of time), and indoor air quality (pollutant ingress from uncontrolled air infiltration).

"Build tight, ventilate right": good airtightness does not mean that homes are sealed, without opening windows, or stuffy: it means there is little uncontrolled ventilation. It allows to control heat loss, while good indoor air quality can be achieved through supplemental ventilation e.g. openable windows, mechanical ventilation.

Very good airtightness can now be achieved – see > Chapter 3 on ***setting objectives***.

Achieving very good airtightness will require attention from the design stage, and it can worsen over time in existing buildings, as materials deteriorate particularly if they were poorly installed or specified. This technique therefore applies throughout the project stages, not just during construction and at completion.

N = 62 (12 Passivhaus and 50 Non-Passivhaus)



Relationship between measured air permeability and measured space heating: the relationship is particularly strong among Passivhaus dwellings (because heat loss through other elements is so small), but is present across the whole sample.

Source: State of the Nation, 2020

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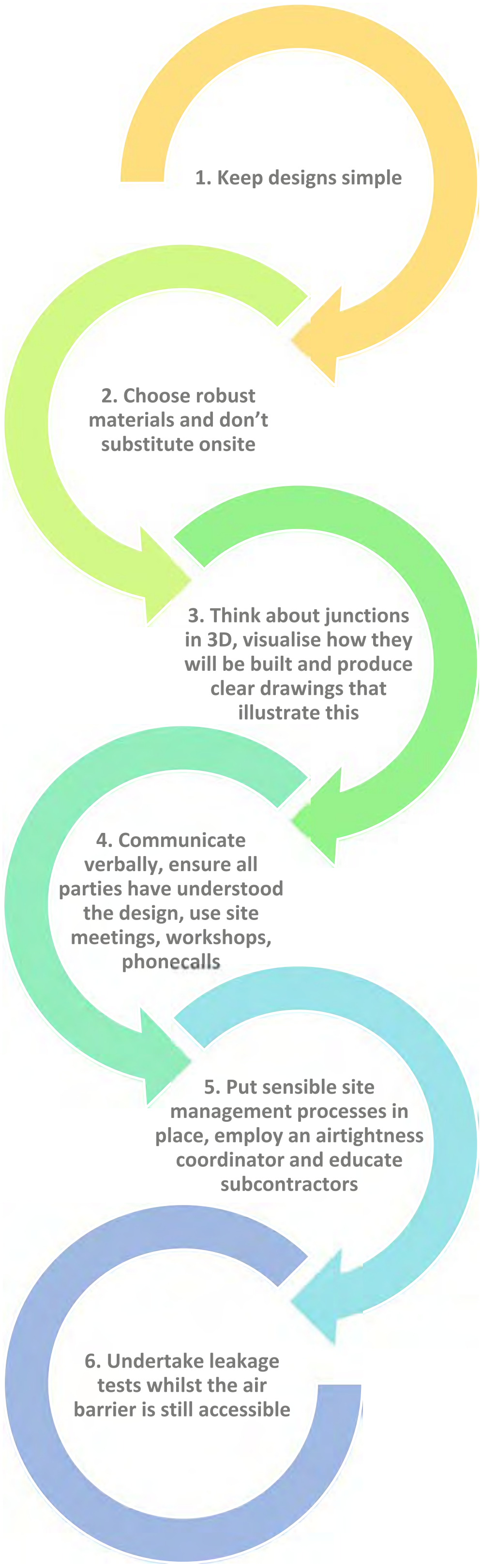


Illustration of "6 things to get right" to achieve good airtightness
Source: Passivhaus Trust, Good Practice Guide to Airtightness, 2020

Project teams should consider appointing an airtightness champion, especially on schemes with onerous targets such as Passivhaus. This person would have a special interest and focus on air tightness and a role to bring attention to any design or construction decision that could impact on it. They should ideally be an integral part of the project team so they are constantly in the project loop.

Specific considerations for timber construction

Very good airtightness can be achieved with timber frame buildings, illustrated by the fact that many certified Passivhaus buildings are timber framed, and Passivhaus systems are available for timber frame buildings. However, an important consideration is that the moisture content in timber will vary over time due to heating cycles, wetting etc. This variation in moisture content can result in movement which can impact the airtightness of timber framed homes.

Timber-based materials delivered to site such as Oriented strand board (OSB) or Cross Laminated Timber (CLT) can vary by batch and design, even with good-quality products, and again vary due to storage and exposure on site. In addition, the installed products may shrink in the first period of occupation due to heating, which could cause air leaks at some junctions. This risk can be managed through good detailing at the design stage and during construction – see references for guidance on design details.

This associated risk warrants re-testing of airtightness as part of the in-use BPE after at least one year of occupation; re-testing should also be done after a co-heating test (see > Detailed BPE - ***section 5.4***).

4.8.2 Guidance and application – design stage

No airtightness testing is done at the design stage, but it is essential to consider airtightness at that stage.

Prompts to typical issues to look for are included in the > technique one pager – ***airtightness***. The Passivhaus Trust, Good Practice Guide to Airtightness, 2020 provides much more detailed guidance on designing for airtightness, including architectural details and materials specification.

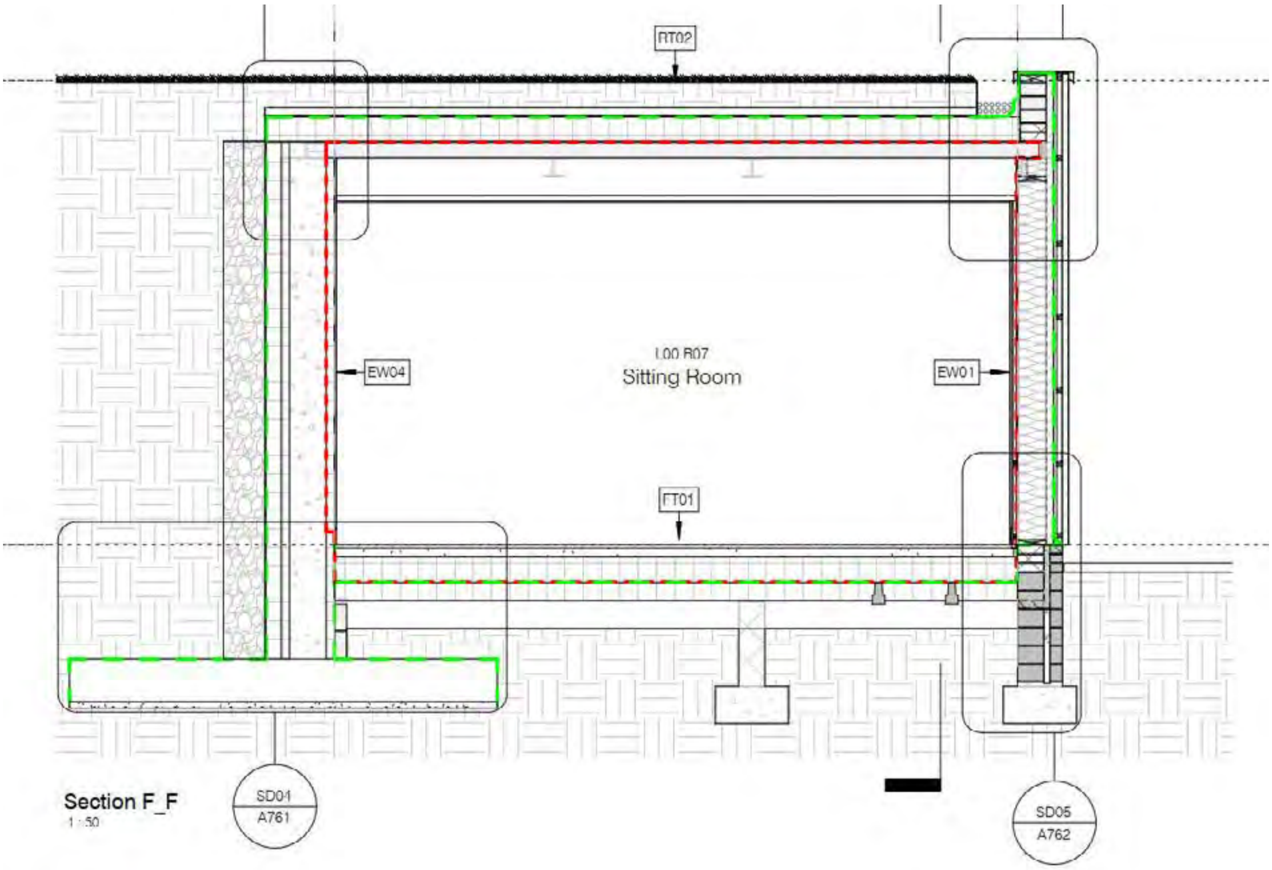


Illustration of what to look for in a review of airtightness at the design stage: drawing clearly showing the airtightness layer, with a red dotted line Source: Passivhaus Trust, Good Practice Guide to Airtightness, 2020

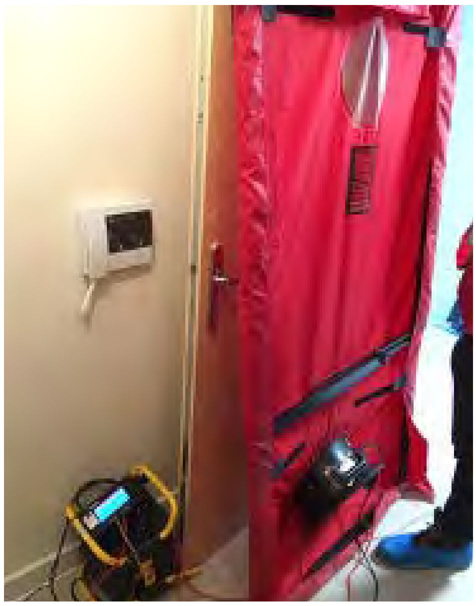
4.8.3 Guidance and application – in construction

Types of tests

The most common method for testing air tightness is the "blower door test", or "fan pressurisation test", which is currently the method used for building regulations purposes. This is carried out with the building pressurised to 50 Pascals (meant to represent a very windy day) Testing involves blocking all air inlets and outlets (e.g. doors, trickle vents, ventilation grilles), pressurising (or depressurising) the dwelling, and measuring the airflow needed to maintain the pressure inside over time. Tests for building regulations can be either pressurisation or depressurisation tests; Passivhaus uses an average of both, and this is recommended as best practice.

Ideally, smoke tests or sensing with fingers should be used at the same time in order to identify the sources of air leakage, so that remediation can be carried out if needed - see tips further down in this section.

Less disruptive low-pressure pulse test methods may be available in the future and accepted for Building Regulations purposes - see > section 6.1 ***Innovative methods: Pulse***. Their potential benefits are to represent air leakage closer to "normal" pressure conditions, and for testing to be carried out more regularly during construction and in occupation.



Home Grown Homes – Pentland Close: Blower door installed for airtightness test (courtesy of Diana Waldron)

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BPE airtightness testing and checks during construction

While testing at completion is required for Building Regulations purposes, this limits the potential remediation measures that can be applied. As homes target increased levels of performance and airtightness, airtightness inspections, checks and tests during construction are strongly recommended.

Airtightness should also be an important consideration as part of the overall site inspections, which may not be carried out by a specialist but could help spot some of the issues, particularly if there is no airtightness specialist involved – see prompts during site visits in > ***Technique One Pager Airtightness***.

As a general rule, testing should be carried out when the airtightness layer is still exposed and accessible, to identify sources of leakages and most easily remediate them. This is one of the advantages of designing the thermal layer outside the airtightness layer, so the airtightness layer can be easily inspected. Conversely, air pressure testing is not recommended too early i.e. before the building envelope is complete, particularly if it relies on temporary measures, as the results would not be representative of actual detailing and built quality. The ideal approach is incremental, in order to check various layers of work and take remediation measures when they are the easiest:

- **Informal checks:** site inspections should be carried out on known common sources of leaks and risky details – see prompts in > ***Technique One Pager - Airtightness***, and informal checks (e.g. using fingers or smoke pens) should be done to spot early issues when they can be easily remediated.
- **Preliminary blower door test:** Once the airtightness layer is complete (i.e. once all windows and doors have been fitted and the building shell is weatherproof) but finishes to floors, walls and ceilings are not yet in place and services are not yet installed. This should be done by a specialist airtightness tester, who would produce a leakage report (including photographs). Additional tests could be carried out, beforehand or afterwards, depending on the scale and complexity of the project e.g. e.g. testing of elements and mock-ups, testing of the first window installations
- **Follow-up blower door test:** Once all service penetrations in the fabric have been made and taped (i.e. all electrical, plumbing, ventilation and miscellaneous pipes and cables have been fitted through the walls, floors and roof).
- **Final blower door test at completion**, for compliance with Building Regulations and other project targets.

On larger schemes it is a good idea to carry out tests on a sample of the first dwellings being built, in order to train teams and possibly remediate construction details or techniques.

What to do with the results ?

Provided the right attention has been given to it in the design and construction stages, it is possible to achieve very good airtightness, and for results to be close to those initially targeted (or even better). Unless very good reasons are identified, such as fundamental issues with the design and construction which are very difficult or impossible to remedy, the aim should therefore be to achieve the initial objective.

Airtightness testing results are reported in terms of the volume of air which escapes the building; this can be as:

- q50: often called air permeability: volume of air per envelope area, per hour i.e. in $m^3/m^2/hr$ at 50Pa. This is used in Building Regulations calculations (SAP).
- n50: air change rate per hour (ach). This is used by Passivhaus.

Information box - How do q50 and n50 compare

V50 = volumetric flow leakage rate, in m^3/hr (at 50Pa)
A = envelope area (including roofs and floors), in m^2
V = volume of the dwelling.

q50 = V50 / A, in $m^3/m^2.hr$
n50 = V50 / V, in air change rate per hr

Because of the common configuration of dwellings, A/V is close to 1, so the q50 and n50 values are not hugely dissimilar. The difference in numbers increases the more leaky a building is, but the ratio between q50 and n50 will remain, since it relates to the dwelling configuration itself.

This varies much more in larger non-domestic dwellings.

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Airtightness results should be compared with the initial target. In most cases, air leakage will be higher than the target. However, in some cases the airtightness may be better than initially intended. In that case it is really important to check the ventilation strategy to ensure sufficient fresh air and removal of humidity and other indoor pollutants. This is especially the case if the building is naturally ventilated. Where air leakage is higher than targeted, sources of leaks identified so that remediation measures can be applied. The specialist airtightness tester will be able to advise more specifically e.g. use of temporary tapes on significant leaks before re-testing, pressurisation to identify failure points.

There are several ways to find leaks, including:

- Smoke testing: this can be used during the pressurisation test
- Smoke pens, used to go round junctions
- Simple check with fingers: if it is cold outside, it should be possible to identify some leaks by feeling cold areas
- Thermal camera: this will highlight cold surfaces along the air path (this does not require a full thermography survey by a specialist, and can be done with a relatively simple thermal camera, with a little bit of training and focusing on known air leak risk areas) - see > ***Detailed BPE - spot checks***.

This can be done by an experienced airtightness tester, or it is possible to rent fans and train site workers, which may allow for more flexibility, reduce costs, and improve overall build quality on the project and future ones.

In general, finding leaks should involve looking at all junctions and penetrations, including around doors and window frames, floor-to-wall junctions, around penetrations for ducts, cables and pipes etc. Fixings such as screws and nails into the airtightness layer are not necessarily a problem but do need attention: those into an airtightness membrane need taping around; those into a layer such as plaster, screed, concrete or CLT need to be firmly fixed.

Finding leaks can be time consuming, particular when very good airtightness is targeted, hence why emphasis should be put at the design stage and site inductions to ensure that the right procedures are followed and the installation and materials are as per design.

Illustration of one possible approach to identify source of leakage: smoke pen. (Source: Enhabit)

When leaks are found and the reason identified, the results and remediation measures should be taken into account in the site procedures, training for the site team and changes to construction details, if required. On larger schemes, they should be taken into account in the construction of the later homes.

Remediation measures will depend on the cause of leak and the stage at which the test is carried out, hence the benefits of carrying out staged tests as construction progresses. At its simplest, it may involve additional taping; in other cases, a new installation may be required e.g. if tape or membranes had been installed on dusty surfaces and did not adhere to it.

4.8.4 Guidance and application – completion and handover

This is when the final blower door test should be carried out.

What to do with the results ?

Results should be checked against the initial target, to determine whether remediation is needed before sign-off.

See guidance on the construction stage on finding leaks and applying remediation measures. Beware the use of temporary "fixes", which may be installed in order to pass a test and may be removed later, or deteriorate rapidly.

Lessons on what worked and didn't should be recorded for future projects e.g. training needs, construction details, selection of materials, site procedures.

4.8.5 Guidance and application – in use

It is useful for the BPE team to carry out an airtightness test at the in-use stage, even if some were carried out at the building completion: this allows a check on the as-built results and, importantly, it can help check whether changes to airtightness occurred in the first period of occupation, in particular as materials dry.

This is particularly true in timber frame buildings, as the timber may shrink as it dries; although good detailing may limit this risk, it is useful to check in use.

Re-testing of airtightness must also be carried out after a co-heating test.

What to do with the results?

See guidance on construction and completion stages, in previous sections.

4.8.6 How to make it happen: who to do it, equipment, cost and time implications

A formal fan pressurisation test ("blower door test "), whether for regulations or to demonstrate compliance with contractual requirements, must be done by a specialist. It should be carried out by a registered tester under the BCS ATTMA scheme (Air Tightness Testing and Measurement Association), and the recommended standard is ATTMA Technical Standard 1 (TSL1), both for Building Regulations and Passivhaus. Passivhaus also requires the ATTMA TSL4 Passivhaus add-on.

Air pressure testing of a home with a blower test can be done in half a day. If the home is already occupied, it should be scheduled in agreement with the inhabitants as it is relatively disruptive since the home must be sealed for this purpose, with no one entering or leaving the home during this period.

The more informal checks, which are recommended throughout construction, can be done by site teams with suitable training – this is encouraged as it will raise the overall level of build quality and performance. This can happen alongside regular inspections by other individuals experienced in airtightness e.g. experienced site teams, Passivhaus designer or certifier, air pressure testing specialists.

4.8.7 Regulatory requirements

In Wales, a maximum acceptable airtightness limit is set in Building Regulations Part L1, and testing is required at completion of the dwellings. While regulations have so far allowed testing of sample dwellings, the 2019/20 consultation proposes that every dwelling should be tested.

Building Regulations currently refer to the blower door test, but may start to accept low-pressure pulse tests as alternative in future revisions to Part L1; At the time of writing, this is expected soon, but is being consulted upon.

4.8.8 References and Further Information

CIBSE TM23 *Testing buildings for air leakage, 2000*. A consultation was carried out in 2019 on revisions to TM23 to accompany the revisions to Part L and F in England and Wales.

BS 9250:2007 Code of practice for design of airtightness

DIN 4108-7, 2007 Airtightness of buildings – requirements, recommendations and examples

Air Tightness Testing and Measurement Association (ATTMA) for methods and accreditation requirements (free, but registration required):

- ATTMA Technical Standard L1: 2016 (dwellings) www.bcta.group/shop/attma-technical-standard-l12016
- ATTMA Technical Standard L4: 2018 (PHT) www.bcta.group/shop/attma-pht-technical-standard-l42018/

Passivhaus Trust, Good Practice Guide to Airtightness - June 2020 : this is comprehensive in terms of design considerations as well as measures on site, and includes examples of design details (some of them for timber construction).
https://passivhaustrust.org.uk/UserFiles/File/Technical%20Papers/Good%20Practice%20Guide%20to%20Airtightness%20v10.4-compressed.pdf

TRADA Wood Information Sheet – Moisture in Timber, 2019

Training courses: ATTMA, Certified Passivhaus Tradespersons course.

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4.9 COMMISSIONING

4.9.1 Overview of the technique

Commissioning is an essential activity to ensure systems work efficiently, as intended, and together with other systems (the testing of systems together is sometimes known as a separate activity, "performance / environmental testing"). It follows the certification of the quality of workmanship and installation ("static testing"). It includes "testing and adjusting, as necessary, (to) ensure that the whole system uses no more fuel and power than is reasonable in the circumstances, without compromising the need to comply with health and safety requirements". (Building Regulations Approved Document L1A, 2010)

Good commissioning is essential to provide high quality services and avoid performance gap issues, customer dissatisfaction and post-completion remediation costs. Poorly installed and commissioned systems will operate less efficiently, may not deliver functional requirements, and will require additional maintenance. For example, poorly commissioned ventilation systems deliver insufficient fresh air and can be noisy, which will disturb occupants and may cause them to switch off ventilation altogether. Another example is system balancing for domestic wet distribution systems: if it is not done properly, the system will operate inefficiently and some rooms may not be sufficiently heated, which cannot be resolved through adjustment of TRVs.

Commissioning is an expert activity; it must be carried out by experienced professionals.

While homes historically comprised very little, if any, complex plant and services, modern homes can include a range of systems such as mechanical ventilation with heat recovery and low-carbon heating technologies, and associated controls, all of which require commissioning.

Commissioning must be carried out on all building systems including heating, cooling, lighting and ventilation, and associated controls, meters and BMS. This should include automated fabric elements, such as openings and shading. This should not be under-estimated in the programme. Ideally, in addition to commissioning at completion, it should also be carried out in the first year in different seasons and at full and part loads.

4.9.2 Guidance and application – design stage

Designs should be developed with ease of installation, commissioning and operation in mind.

Approved document L1a (2014), which provides guidance on meeting Building Regulations, recommends that **"A commissioning plan should be prepared in advance, identifying the systems that need to be tested and the tests that will be carried out"**.

On multi-dwelling schemes, particularly those with central services, a commissioning review should be carried out at the design stage to consider how commissioning will be carried out, and ensure that the programme will allow for suitable commissioning.

For ventilation systems, the most important design consideration is how the intake and exhaust flow rates will be measured, as this can often be difficult. For example, the installation of an in-duct measuring device removes the need to measure air flow rates on the outside of the building. This is possible in straight duct lengths before a measuring section. MVHR units which control the air flow rate automatically usually provide a read-out.

Early on in the project it is important to identify a suitable period in the programme to carry out commissioning, and to protect that period as the project progresses.

The project team should also discuss whether additional scope and appointments will be required – see section ***How to make it happen***.

Design and specification information should indicate which manufacturer and/or installer is responsible for each system and interface, and details of each interface.

The installation and commissioning requirements should meet those in Approved Documents F and L and the *Domestic Building Services Compliance Guide and Domestic Ventilation Compliance Guide*. For communal systems, the non-domestic equivalent guides may apply. Manufacturer instructions should also be followed.

GUIDANCE ON CORE BPE TECHNIQUES

Specifying performance criteria

The design team should specify the performance criteria which systems will be tested against; this would usually be aided by the engineer, or sometimes the Passivhaus consultant on Passivhaus schemes. For ventilation systems, this must include the delivered air flow in each room, operating noise levels, and system balancing – the Passivhaus MVHR Good Practice Guide provides detailed guidance (see references).

4.9.3 Guidance and application – in construction

Systems should be tested, checked and commissioned to operate efficiently and effectively by competent personnel. Commissioning happens towards the end of the works, often with pressures on the programme, but the required time must be protected so it can be done properly. On large schemes early homes can be tested and lessons incorporated into the installation of the later phases, but all homes should still be commissioned.

Acoustic testing of the ventilation system should be carried out at the same time – see > ***section 4.10***.

Standards and procedures

Standards and procedures should be as defined by the specifications - see > ***section 4.9.2.***

A dedicated individual, the commissioning engineer, should be responsible for the quality of installation and commissioning, and checks should be made during the installation process to help ensure good practice. It is considered best practice for system designers to be present at the commissioning of the first dwellings on a site, undertaking spot checks on the commissioning of a sample of completed units, and training a champion in the site staff who can make similar additional checks of the installation and commissioning of the later phases. Particular time and care may be needed where systems or products are being used that are relatively unfamiliar to those involved in the installation and commissioning process.

What needs to be done

Commissioning actions required include (according to CIBSE Guide F, 2012; TM60, 2019):

- pressure testing ductwork and leak testing pipework, and cleaning as required
- testing and adjusting equipment to achieve optimized flow rates, temperatures, balancing etc. This must include (but is not limited to) comparing the designed and measured flow rate.
- recording and correcting any defects
- undertaking and recording system settings and performance tests and comparing against designs
- ensuring services operate correctly, safely and efficiently.

Distribution network operator (DNO) commissioning requirements should additionally be followed for distributed electricity generating installations.

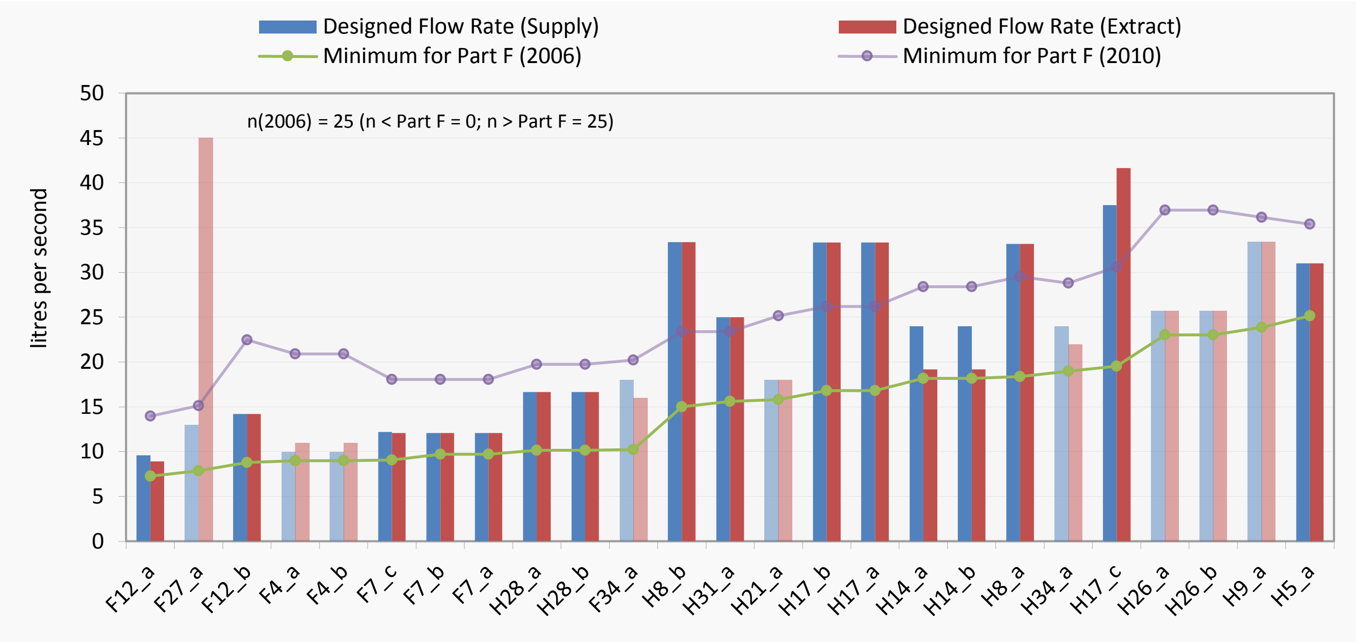
The Domestic Building Services Compliance Guide provides guidance on commissioning requirements for Building Regulations compliance, with a checklist for ventilation systems in the *Domestic Ventilation Compliance Guide*. However, these are aimed at regulatory compliance; on ventilation systems, for more detail on and more focus on performance, see the Passivhaus MVHR guide, 2018 (see references).

What to do with the results?

Commissioning should be carried out until the specified performance criteria are met. A margin of error is normal and may be included in the specifications. For anything beyond this, the commissioning engineer and designer should agree what is a reasonable deviation. In any case, regulatory compliance must be the absolute minimum backstop requirement.

GUIDANCE ON CORE BPE TECHNIQUES

Commissioning of ventilation systems is essential to delivered the intended air flow rates, and often does not happen properly. A meta-study carried out in 2016 of MVHR installations found that only 16% of systems (had) been commissioned correctly with respect to air flow and balancing. Consequently, the performance of the systems investigated (...) varied significantly, with only 56% of installations meeting the design air flow value". This can have serious implications on air quality and mould growth.



Air flow rate (measured) compared to Part F requirements (appropriate to dwellings when Part F 2010 was in force)
(Source: Sharpe, McGill and Gupta, Characteristics and performance of MHVR systems — a meta study of MVHR systems used in the Innovate UK Building Performance Evaluation programme, 2016)

The Passivhaus MVHR Good Practice Guide includes a "troubleshooting" list, but refers to the experience of commissioning engineers as this is a specialised area.

4.9.4 Guidance and application – completion and handover

The BPE team should check that commissioning has been carried out and results meet the required performance requirements as well as the requirements of Building Regulations compliance. In the case of any departure, see > "***what to do with the results***" in the construction section 4.9.3.

Records of commissioning should form part of the handover information and also provided to Building Control for sign-off.

A note should be made of the items which will require seasonal commissioning (e.g. heating systems, particularly multi-residential ones rather than individual boilers); this should be programmed and an appointment confirmed, as it can otherwise easily be forgotten or neglected later on.

4.9.5 Guidance and application – in use

There should be an initial review of documentation (see > ***section 4.2)*** for a brief check that systems appear to have been commissioned as required by regulations (as a very minimum) and information handed out to inhabitants and other users about the operation of their systems. Attention should be paid to seasonal settings, as c ommissioning at completion may have happened in one period, for example winter, without attention to summer and mid-seasons.

Additional activities could involve a quick check on obvious installation errors, faults and control settings, particularly if issues are identified through the other BPE activities e.g. inhabitant feedback on comfort, or spot-checks of temperatures and air quality.

Testing of MVHR air flow using a flow hood. It's important to use a hood which can measure low flow rates, matching those in homes (many hoods are only appropriate for higher rates).

Source: Will South, from the video "Installing a ventilation system (MVHR) in an existing home" *https://www.youtube.com/watch?v=iyi6qdwzM3s*

What to do with the results?

If issues are identified, the next step is re-commissioning. Re-commissioning may need to be carried out if issues are identified in operation or through the review of commissioning records. It must involve appointing a commissioning specialist or engineer.

This should include all systems (heating, cooling, ventilation, controls etc), with checks on individual systems as well as how they operate together:

- review processes and records against the commissioning plan and standards
- review settings against specifications and against manufacturers' recommendations
- visually inspect for errors in installation, damage or faults
- test all systems against specifications and manufacturers' recommendations, and carry out air flow measurements and check balancing of ventilation systems
- update guidance to inhabitants and other users on the operation of their systems, if relevant.

It is possible that this would lead to recommendations for more detailed interventions (forensic BPE) - not detailed here.

4.9.6 How to make it happen: who to do it, equipment, cost and time implications

While the importance of commissioning is widely acknowledged, because it happens towards the end of projects when programmes are already often under pressure, the period available for it is often squeezed and can compromise the ability to carry out full and adequate commissioning. This can have important repercussions on future building performance. While it may be tempting to reduce the time dedicated to commissioning, this should therefore be avoided; the required tasks and period identified at the design stage should as much as possible be protected.

On larger schemes, there should be benefits in thoroughly commissioning the early phases, to improve installation and reduce commissioning time in the later homes.

Commissioning is a specialist activity, typically not carried out by the design team or BPE team.

The design team should advise at the design stage whether additional scope and appointments will be required, including:

- Scope and appointment of the commissioning engineer, including whether they should be appointed to carry out a commissioning review at design stage. In some cases (typically on larger and more complex schemes), the team may advise that a separate specialist be appointed to review commissioning at completion on behalf of the client (not appointed by the contractor).
- Extent of witnessing by designers.

Installers and commissioning engineers should be appropriately qualified and experienced - see References and Further Information section.

4.9.7 Regulatory requirements

Part L of the 2010 Building Regulations 2010 requires that fixed building services "are commissioned by testing and adjusting as necessary to ensure they use no more fuel and power than is reasonable in the circumstances".

4.9.8 References and Further Information

Commissioning codes and guidance:

- All systems: *The Domestic Building Services Compliance Guide* (NBS, 2018) gives information on checklists that can be used as a record of satisfactory installation and commissioning for some systems. *The Domestic Ventilation Compliance Guide* (NBS, 2011) provides an additional inspection checklist and air flow measurement test and commissioning sheet for ventilation systems, which should be completed by installers and test and commissioning engineers.

- Passivhaus Trust - Good Practice Guide - MVHR for single dwellings (Sep 2018) www.passivhaustrust.org.uk/UserFiles/File/Technical%20Papers/2018%20MVHR%20Good%20Practice%20Guide%20rev%201.1.pdf

- Rainwater harvesting systems: the *Rainwater Harvesting: Design and Installation Guide* (DBSP, 2010) provides guidance on good installation practice and typical commissioning activities, and gives a specimen commissioning sheet. Manufacturers' guidance should also be followed.

- CIBSE Commissioning Codes, including Code A: *Air distribution systems* (CIBSE, 2006b), Code B: *Boilers* (CIBSE, 2002b), Code C: *Automatic controls* (CIBSE, 2001), Code L: *Lighting* (CIBSE, 2003a), Code M: *Commissioning management* (CIBSE, 2003b), Code R: *Refrigerating systems* (CIBSE, 2002c) and Code W: *Water distribution systems* (CIBSE, 2010). BSRIA also produces useful commissioning guidance for various systems and components, including BG2/2010: *Commissioning water systems* (BSRIA, 2010b), BG49/2015: *Commissioning air systems* (BSRIA, 2015), and BG11/2010: *Commissioning Job Book — A framework for managing the commissioning process* (BSRIA, 2010c), which gives general guidance on managing the commissioning process. **These Codes are often aimed at large systems and may not be suitable for individual homes, particularly for ventilation systems**.

Qualifications:
Installers should be appropriately qualified and experienced (e.g. for ventilation systems BPEC qualified, and for heating systems Microgeneration Certification Scheme accredited where relevant (www.microgenerationcertification. org) or, for biomass boilers, installers registered with HETAS (HETAS, 2015)). Installations should meet relevant standards such as BS 8000-15 (BSI, 1990) and BS EN 14336 (BSI, 2004) for water-based heating systems, and MCS standards (MCS, 2015) (or suitable alternative) for renewable systems.

Commissioning engineers should be experienced professionals, and it is recommended that they should show recent experience on similar schemes in scale and types of systems.

GUIDANCE ON CORE BPE TECHNIQUES

4.10 ACOUSTICS REVIEW, CHECKS AND TESTS

Noise is one of the issues which attract the highest number of complaints in new homes. Ensuring that noise levels and disruptions from external and internal noise sources or neighbours are minimised is very important for inhabitant comfort and satisfaction.

See > Technique one-pager – ***Acoustics review***.

Related BPE techniques:

- Overheating risk analysis – see > ***section 4.4***
- Commissioning – see > ***section 4.9***
- User feedback surveys – see > ***section 4.13***

4.10.1 Overview of the technique

If not well-considered in the design, external noise can disrupt and annoy residents and disturb sleep; it can also be a barrier to window opening and therefore increase overheating risk or affect indoor air quality.

Issues from insufficient attention to the acoustic design, construction detailing, or commissioning can manifest in various ways in new residential developments, including:

- Environmental noise affecting the site, and any design response to that noise. This may include requirements for ventilation and mitigation of overheating. Excessive environmental noise can be annoying and disrupt sleep. This should be a planning requirement if the site is exposed to high levels of environmental noise, and it is not uncommon for details provided to the planning authority at the design stage to be omitted on site, as there are no regulatory checks for this.
- Environmental noise from building services systems such as air conditioning units and air source heat pumps (ASHPs) affecting the dwelling served by the ASHP, or neighbouring dwellings. This can have a bigger impact in quieter locations where there is less background noise.
- Internal noise from building services – notably ventilation systems. If they are noisy, people turn them off, and suffer the effects of poor indoor air quality in modern airtight dwellings. There are currently no statutory standards for noise from ventilation or heating systems, nor a requirement to measure this noise.

- Sound insulation between attached dwellings, to afford acoustic privacy between demises. Building Regulations provide minimum performance requirements for airborne and impact sound transmission, but there can be issues despite complying with Building Regulations.
- Sound insulation within dwellings – to afford a lower level of acoustic privacy to bedrooms and toilets (compared to between dwellings). Building Regulations provide minimum design standards for wall and floor details, but no standards to be achieved in practice.
- Noise arising from the use of the dwelling – e.g. creaky floors or stairs, noise from water flowing in pipes, from WCs, from radiator pipes

Specific considerations in timber construction:

Twin stud walls usually generally perform well in acoustic terms. Floors in timber framed homes need more attention as there is a propensity towards footstep transmission to rooms below. For more information see > references and section 4.10.2 on ***design guidance***.

4.10.2 Guidance and application – design stage

Consider if any particular aspect of acoustic performance requires consideration beyond the minimum regulatory standards, where the exist. In particular, noise from mechanical ventilation systems is one aspect that is currently not controlled through Building Regulations, but can be problematic for occupants.

GUIDANCE ON CORE BPE TECHNIQUES

Potential acoustic issue	Design stage considerations and implications
Environmental noise	If environmental noise is identified in the planning process, how does the design respond to this? E.g. is it possible to locate bedrooms on quieter façades? Does the ventilation strategy mitigate external noise ingress? Do the noise levels indicate that reliance on opening windows to mitigate overheating is appropriate or not? The Acoustics, Ventilation Overheating: Residential Design Guide (AVO Guide, see References) describes this assessment. Has this been considered in the assessment of site noise levels?
Building services noise	Are criteria adopted for the impact of noise from external plant, such as Air Source Heat Pumps? Identify who is responsible for the acoustic design of the systems and for setting performance criteria. Identify standards for noise from building services e.g. from the AVO Guide and from CIBSE TM60.
Sound insulation between dwellings	Identify who is responsible for the acoustic design of the systems. Commit to acoustic commissioning of mechanical ventilation systems, particularly if using MVHR, in combination with the air flow commissioning. Standards for noise from mechanical systems implies consideration of where building services are located – especially ventilation units, but also pumps and underfloor heating manifolds. Building Regulations specify the minimum performance for airborne sound insulation of walls and floors, and impact sound insulation of floors between dwellings.
Sound insulation within dwellings	Twin stud timber walls provide intrinsically high levels of sound insulation between dwellings.
Internal noise	Timber party floors can easily meet Building Regulations, but there is a risk of low frequency noise transmission that is outside the scope of the Building Regs. There can be poor protection from noise from footsteps. Standards from the (soon to be published) ISO 19488: Acoustic classification of dwellings may be adopted; consider Class C for a reasonably good standard. Twin stud timber walls are likely to achieve Class C performance, while typical timber floor details are unlikely to meet Class C for impact sound performance. Building Regulations provides a minimum sound insulation performance for internal walls and floors to bedrooms and bathrooms, but nothing to be achieved on site. If internal sources of noise are found to be problematic, consider adopting a performance Class from ISO 19488: Acoustic Classification of Dwellings for this aspect.

4.10.3 Guidance and application – in construction

Noise issues can easily arise where the design intent is not realised on site. When acoustic details have been submitted to the local planning authority, these can easily be forgotten during design development – the planning authority does not check that particular details are built on site.

Potential acoustic issue	Design stage considerations and implications
Environmental noise	Do the construction details for façade elements – in particular glazing & and trickle vents – meet the design requirements? Does the noise data for the particular ASHP comply with the requirements?
Building services noise	Check any design development and proposed products can meet the performance requirements, if adopted. Carry out acoustic testing of ventilation systems during commissioning, to check performance criteria are met. Any systems not meeting the target noise levels should be adjusted - possible reasons for noisier operation are loose fixings, ductwork that is too narrow and pipework without sufficient space to expand and contract. For ventilation systems, it is worth paying attention to fan speed settings used as higher settings are likely to be noisier in operation. Ask installers/commissioning engineers to provide fan speed settings for each unit as variation in the values used between similar units could indicate issues. See also section on > ***Commissioning***.
Sound insulation between dwellings	As this is either tested on completion or compliance achieved through the use of Robust Details, building contractors usually take good care to mitigate their risk in this regard. If different or higher performance standards are adopted, who is reviewing the design against those standards, and who is checking on site that the details are appropriately constructed?
Sound insulation within dwellings	General good practice for sealing partitions and penetrations
Internal noise	General good practice for fixings for water services (See CIBSE TM60), ducting and flooring should minimise the potential for adverse noise from use. Anecdotally, if timber floors get wet during construction, it can be very difficult to overcome creaking noise when walked on in the completed building.

GUIDANCE ON CORE BPE TECHNIQUES

4.10.4 Guidance and application – completion and handover

Check that commissioning has confirmed that acoustic performance targets have been met including any necessary remedial work.

4.10.5 Guidance and application – in use

Perceptions of noise are complex, so feedback from occupants should be the main driver: homes that in theory meet specifications and regulatory requirements may still give rise to complaints, as not all sources and types of noise (or vibration) can realistically be covered on the specifications of all project.

Ask inhabitants whether they have any issues with noise in their homes – this can be asked during the site visit, along with the BPE team's own observations, as well as during the formal user surveys - see ref core > ***user feedback surveys***. Correlate feedback from the residents with the following:

- acoustic testing of the ventilation system
- site observations
- airtightness test (very airtight homes tend to attenuate outside noise well).
- Notes from the design and handover review on the approach taken to meet Building Regulations requirements i.e. Robust details or testing.

Noise complaints relating to ventilation should first be addressed by reviewing commissioning and, if needed, re-commission the system. If that is not sufficient, more detailed investigations may be required such as the installation and type of ducts. Sometimes, loose elements are the issue; in other cases, the design or installation itself may need rectifying.

Noise complaints relating to the building fabric can be more complex and difficult to remedy, and must involve an acoustic specialist. To identify possible remediation measures and lessons for future schemes, it can be useful to classify noise issues as party walls and floors (E1) / within dwellings (E2) / creaking floors / Creaking stairs / Water pipes and WCs / ventilation / heating and radiators / other.

Illustration of acoustic testing: Sound insulation testing between apartments involves generating loud noise with a speaker, and measuring the sound level difference across the party wall. It will not usually be a core BPE requirement, but is advisable where there is any concern about noise transmission between adjacent units. An acoustic specialist will advise whether this is required. *(Image courtesy of Apex acoustics)*

4.10.6 How to make it happen: who to do it, equipment, cost and time implications

Noise is a complex area, and it is recommended to seek advice from a professional acoustics consultant, particularly on sites exposed to external noise e.g. urban areas, where expert advice may be needed on the best approach to noise, ventilation and overheating. The ANC (Association of Noise Consultants) has a list of consultant here: www.association-of-noise-consultants.co.uk/

4.10.7 Regulatory requirements

Building regulations require mandatory sound testing between attached dwellings, or the use of 'robust details' to demonstrate compliance.

Building regulations do not currently cover external noise (covered by planning), or noise from mechanical ventilation systems (besides product testing).

4.10.8 References and Further Information

NHBC review of homeowner feedback on noise in new homes:
www.nhbcfoundation.org/publication/sound-progress/ (needs NHBC login or registration)

ANC guidance measurement of sound levels in buildings:
www.association-of-noise-consultants.co.uk/wp-content/uploads/2019/12/ANC-Measurement-of-Sound-Levels-in-Buildings-v1.0-June-2020.pdf

Apex Acoustics paper on Impact Sound Insulation In Timber Frame Flats:
www.apexacoustics.co.uk/wp-content/uploads/2015/12/Low-frequency-impact-sound_Apex-Acoustics-Proc.-IOA_2015.pdf

CIBSE TM60:2018 Good Practice in the Design of Homes
www.cibse.org/knowledge/knowledge-items/detail?id=a0q0O00000Di83DQAR

ISO 19488: Acoustic Classification of Dwellings - currently under preparation for its final publication.

GUIDANCE ON CORE BPE TECHNIQUES

4.11 ENERGY USE AUDIT

4.11.1 Overview of the technique

Energy consumption is an essential metric for understanding overall building performance, running costs and carbon emissions. Homes often consume more energy than expected, which can only be uncovered and improved upon with routine monitoring and analysis. This is made more challenging by the wide range occupancy factors that can impact on energy consumption; the more homes that can be included and aggregated, the more these effects are averaged out; on small schemes, care must be taken to consider occupancy factors and not over-interpret results: in these cases, tests focusing on fabric and services performance alone will be all the more important.

An essential part of BPE is therefore to carry out a simple energy use audit, based on annual measured energy consumption as a minimum. It allows an assessment of performance and comparison against design targets and benchmarks:

- Work with inhabitants or, on multi-home schemes, the FM team, to collect annual energy consumption data based on meter readings for as many units as possible, covering at least one year in occupation.
- Carry out an initial analysis including comparison against annual energy use targets, and correlation with other BPE findings (e.g. fabric performance, occupant comfort, commissioning, water consumption).

This should be done for individual homes and, on multi-home schemes, on an aggregated basis for the scheme.

There are several levels of detail at which this can be carried out:

- as a minimum, using annual readings for the main meters of each energy supply; at its simplest, this could be based on energy bills, provided they are based on actual rather than estimated readings. This is recommended as core BPE and described here
- for more in-depth studies, including an analysis of the breakdown into uses, patterns of consumption across the week and in different seasons etc – see > ***detailed BPE***.

There are privacy and ethics implications to using this data and care should be taken to ensure appropriate permissions are sought and GDPR complied with - see > ***ethics & privacy*** section 1.4.

Specific considerations in timber construction:
None

4.11.2 Guidance and application – design stage

n/a as this technique applies at the in-use stage, but see > Core BPE ***Energy strategy review*** for design considerations to facilitate in-use BPE, especially metering.

4.11.3 Guidance and application – in construction

n/a as this technique applies at the in-use stage, but see > Core BPE ***commissioning for construction*** considerations to facilitate in-use BPE: It is essential that any installed energy meters are calibrated and commissioned, as reliability of data will otherwise be compromised.

4.11.4 Guidance and application – completion and handover

It is essential that any installed energy meters and any associated logging systems are calibrated and commissioned, as reliability of data will otherwise be compromised - see > Core BPE ***Commissioning.***

Following completion, the first year of occupation should be used to make sure that things are in place for the 2nd year energy audit i.e. meters are commissioned, a check has been done that sub-meters (if any) are reconciled (i.e. they add up), a sense check has been carried out on the readings and the associated logged data (e.g. it is not uncommon for periods of missing data), and permissions are in place to access and use the data. This will ensure that the actual energy audit is based on available and reliable data.

4.11.5 Guidance and application – in use

The core energy audit requires annual energy consumption data, covering at least one full year of occupation. This can be gathered by the BPE team from meter readings, or alternatively energy bills may be used, provided residents agree and the bills are based on actual readings.

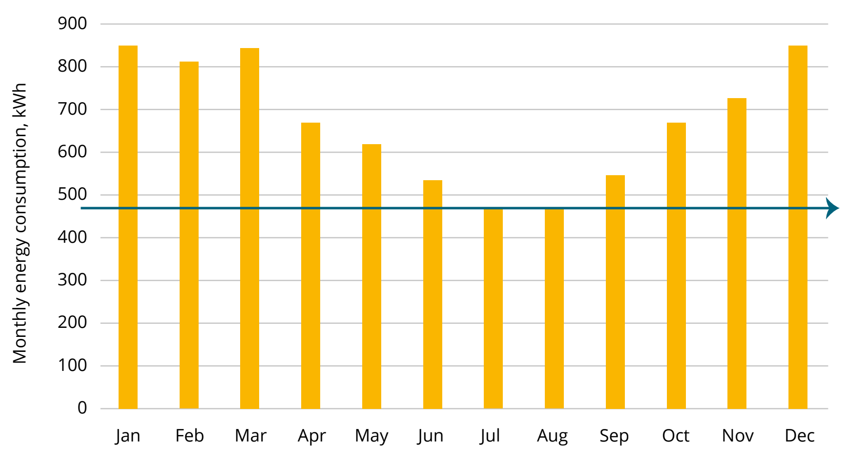
Ideally the audit would exclude the first year, when users are "settling in" and learning to operate the building, and some systems may still be getting fine-tuned, and the building still drying out – see previous section on recommendations in the 1st year, to put things in place for the audit.

The analysis must differentiate between consumption related to hot water and space heating (thermal consumption), and that associated with other electrical uses. Catering gas would also ideally be differentiated, although this is unlikely to be sub-metered except on large schemes.

Except on large schemes, there is usually no separate metering of space heating and hot water; this may be installed in a more detailed study but usually not in core BPE. However, an estimate can be obtained from profiles of thermal energy use throughout the year, as consumption in the summer month, at its lowest, will be hot water (and cooking gas, if applicable) – see illustration.

Illustration of how to estimate the breakdown between space heating and hot water from total thermal energy consumption (e.g. gas consumption): using monthly consumption figures, the profile can show the lowest consumption points, which can be assumed to be hot water (and possibly gas for cooking, if present). A certain level of detail can be added if, for example, the BPE team know periods when the residents were away, or can check when residents had space heating off (in case of unusually cold days in mid season, for example).

Efficient homes should show a larger share of energy consumption domestic hot water than less efficient ones. They should also show longer periods without energy being used for space heating.



The lowest point gives a rough estimate of monthly energy consumption for hot water.

Multiplied by 12, this gives the annual figure. That figure can then be subtracted from the total annual consumption, to give an estimate of energy consumption for space heating.

Source: illustrative graph produced using Bizee degree days data from Cardiff for the past 12 months, assuming no heating in July and August and a total annual gas consumption for an Ofgem "low" profile)

Separate out any on-site generation so that it is possible to report on the net and total energy demand for the scheme. Where possible, where there are sub-meters, check whether they add up. See illustration in the energy strategy > ***section 4.5.2***.

What to do with the results?

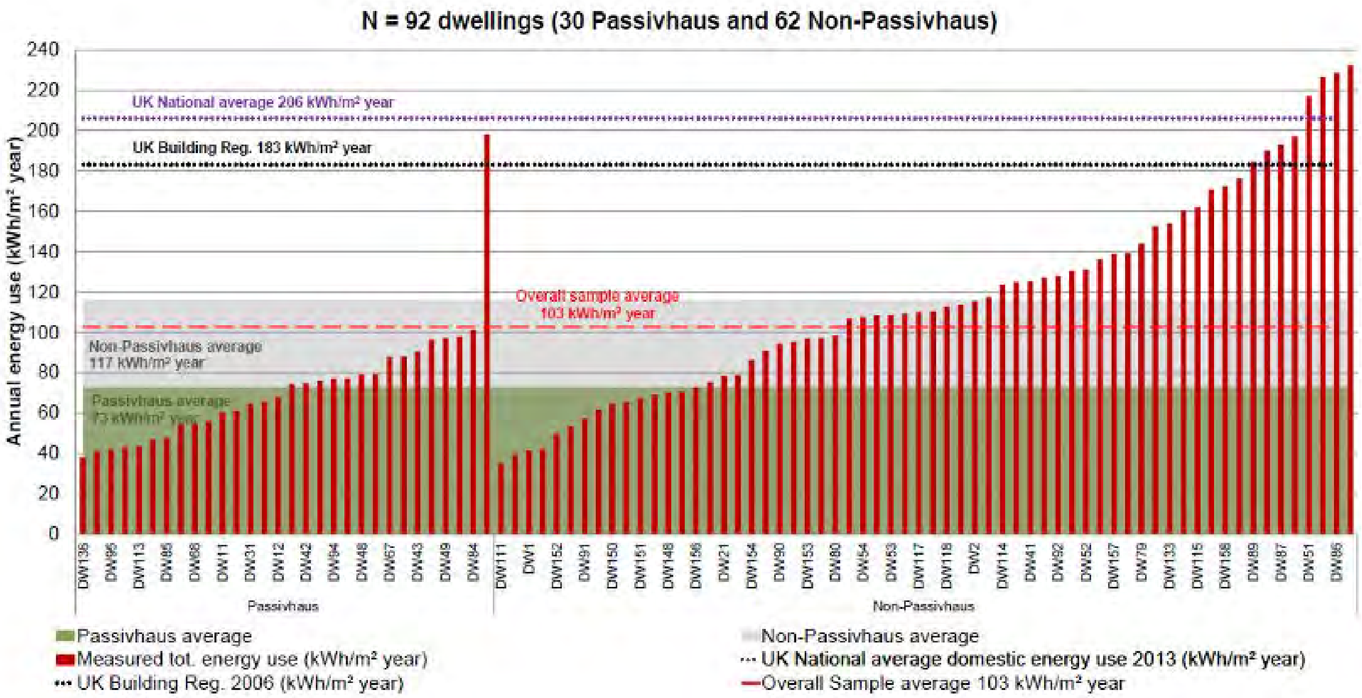
Care should be taken not to draw excessive conclusions from the initial audit, particularly in the case of a single home or small sample of dwellings. There will be variations from one year to the next due to weather - see advice further down on taking account of this through heating degree days. In addition, and most importantly, there will always be large variations in energy consumption, even between two identical dwellings, due to occupancy patterns (density, lifestyles patterns such as stay-at-home vs out-working-all-day, heating set point preferences etc).

On schemes with several dwellings, it can be very useful to look both at average consumption of dwellings over the whole scheme, and the distribution. For example, while the heating demand of Passivhaus dwellings varies a lot from one dwelling to another, their average consumption is very close to that predicted, and the "spread" tends to be tighter than for less well performing dwellings: there is less difference between lowest and highest consumers - see illustration on next page.

GUIDANCE ON CORE BPE TECHNIQUES

The analysis must differentiate between consumption related to hot water and space heating (thermal consumption), and that associated with other electrical uses. Catering gas would also ideally be differentiated, although this is unlikely to be sub-metered except on large schemes.

Except on large schemes, there is usually no separate metering of space heating and hot water; this may be installed in a more detailed study but usually not in core BPE. However, an estimate can be obtained from profiles of thermal energy use throughout the year, as consumption in the summer month, at its lowest, will be hot water (and cooking gas, if applicable) – see illustration.



Source: State of the Nation report, 2019

Energy consumption, including total energy use and (if possible) its breakdown into end uses, can be compared to current and best practice, and to the targets set at the design stage as well as any energy prediction - see > core BPE ***energy use audit*** and section 3 on ***performance objectives and benchmarks***.

The analysis is usually done by using energy performance in kWh/m²/yr and kWh/dwelling/yr, but other metrics may be used in parallel: for example, kWh per year per inhabitant if the home is occupied at particularly low or high density.

Alongside benchmarking, results should be put into context, including weather, patterns of use, and correlation with findings from the other BPE techniques.

Taking the weather into account

Heating degree days are a very useful and simple way to take account of the weather when looking at energy consumption for heating.

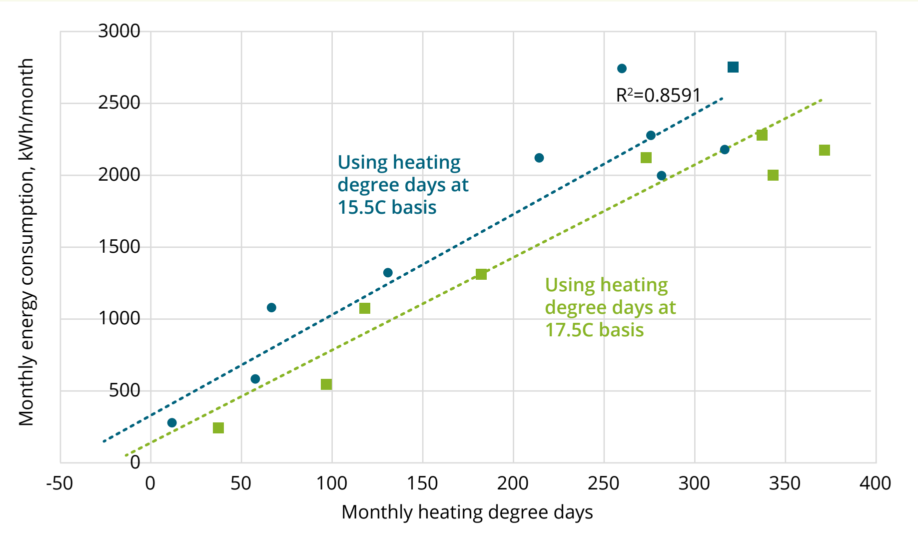
The use of heating degree days provides a means to normalise the heating energy consumption used for the weather that year. Heating degree days is a measure that takes into account how cold a year is, both in terms of how low temperatures get, and for how long. As 1kWh measures a kW of energy being used for a whole hour, one degree day represents a whole day where the temperature fell 1°C below the point when the heating could have come on (base temperature).

The base temperature is usually taken around 15.5ºC in the UK, although in modern efficient homes, heating should not have to be on at that temperature and a lower base can be used: roughly speaking, the base temperature is that below which, for this dwelling in the way it is currently operated, heating starts being used. Reports should always state the base temperature, when using degree days.

A long cold winter will measure a much higher number of degree days than a short mild one, and the amount of space heating needed for a winter will be correlated to the number of degree days. This is important as a new efficient heating system could use more energy than expected if the winter monitored is particularly cold, taking the degree days into account allows the energy used for space heating to be normalised and compared more fairly.

There is a good introduction to degree days and some useful resources on Bizee: www.degreedays.net/introduction . It is also a freely available source of degree days data for multiple locations in the UK, with data going back to at least 24 months.

Illustration of one way to use degree days: the graph shows 2 curves, which show the same monthly space heating energy consumption for the same building, but plotted against monthly heating degree days at 2 different base temperatures. Space heating consumption follows a reasonable correlation with heating degree days, which tends to indicate heating is switched off or down when not needed. However, the curves also show that the base temperature for which the curve crosses the x-y "0" intersection point is around 17.5oC: this is fairly high, against a UK typical base temperature of 15.5oC. This would tend to indicate residents use reasonably high heating space points and/or the building loses heat rapidly, requiring residents to turn it on often. These observations are not necessarily conclusive on their own, but useful to correlate with other findings.



A more efficient dwelling would have lower energy consumption at similar heating degree days i.e. the curve would be lower at similar heating degree days. For that dwelling, the base temperature for which the consumption curve would cross the x-y "0" intersection would be lower.

A poor correlation can indicate a number of things: the heating system is not operating well or not well managed e.g. on when it shouldn't need to be; the consumption data includes energy consumption not related to space heating (e.g. cooking).

Degree days can be used in different ways:

- To compare consumption between years, by checking whether one was colder than the other i.e. had more heating degree days
- To compare consumption between months or even weeks, to check trends. For example, all other things being similar, lower space heating consumption at similar degree days would indicate a more efficient and/or better managed building.

Note that as for any analysis of energy consumption, this must also consider non-technical issues, such as user behaviour. For example, energy consumption may be low if residents are in fuel poverty and as a result not heating their home to comfortable levels.

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Looking at patterns

If it's possible to do so through smart meters or access to regular readings, more understanding of energy consumption can be gleaned by looking for patterns in the data – for example how does energy use compare:

- Weekday / weekend
- Day / night
- Summer / winter
- Exploring these patterns is helpful alongside the user feedback surveys ref > core BPE ***user feedback surveys*** as the two can corroborate or help diagnose any issues that come up.

Correlation with other BPE findings

Findings from the energy audit should be examined alongside those from the other BPE techniques, so that energy performance is looked at holistically taking account of fabric performance, building systems, and occupant feedback and behaviours.

E.g:

- High space heating alongside fabric performance
- High energy for hot water alongside water consumption
- High electrical uses throughout vs observations and feedback from user surveys: is the home occupied for long hours and /or at relatively high density?
- documentation review
- spot-checks on the internal environment
- Feedback from inhabitants about how they occupy their home and whether their energy bills are higher or lower than they expected – from the > ***Core - Site visit-In use*** and Core BPE > ***user surveys***.

Next steps

Where design stage targets are not met, some investigation should be carried out using the other BPE findings, leading to the identification of a number of likely causes (e.g. issues with installation or settings, users unfamiliar with the operation of systems), remediation options, and areas which warrant a more detailed investigation of energy consumption (e.g. energy monitoring – see > ***detailed BPE***, possibly alongside detailed energy calculations or modelling – see > ***detailed BPE*** .

4.11.6 How to make it happen: who to do it, equipment, cost and time implications

This is a relatively low cost technique in terms of equipment - especially if smart meter data can be utilised. It can take some time to organise (permissions/access etc), to collate the data and to analyse it. The preparation phase i.e. making sure data will be available, reliable and meaningful, must not be under-estimated when procuring the BPE work.

It can be carried out by any design professional, but some experience in BPE is recommended in order to analyse the results effectively and correctly, correlate them with other findings, and not over-interpret.

4.11.7 Regulatory requirements

None

4.11.8 References and Further Information

TSB Innovate UK domestic BPE - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/497758/Domestic_Building_Performance_full_report_2016.pdf

Housing Fit for Purpose by Fionn Stevenson, 2019 (RIBA Publishing)

State of the Nation, 2020 https://building-performance.network/research/state-of-the-nation-domestic-buildings

GUIDANCE ON CORE BPE TECHNIQUES

4.12 WATER USE AUDIT

4.12.1 Overview of the technique

Water consumption is an important metric for understanding overall building performance and environmental impacts. Water consumption has environmental impacts in itself, and is also responsible for carbon emissions through the treatment and distribution of water. In southern densely populated parts of the UK, water available per person is already relatively low, and reductions in demand and consumption are needed to avoid shortages in the future.

An essential part of BPE is to carry out a simple water use audit, based on annual measured water consumption. It allows an initial assessment of performance and comparison against design targets and benchmarks:

- Work with inhabitants or, on multi-home schemes, the FM team, to collect annual water consumption data based on meter readings for as many units as possible, covering at least one year in occupation.
- Carry out an initial analysis including comparison against annual water use targets, and correlation with other BPE findings (e.g. occupant feedback, energy consumption for hot water, site observations on water fittings and appliances).

This should be done for individual homes and, on multi-home schemes, on an aggregated basis for the scheme.

There are several levels of detail at which this can be carried out:

- as a minimum, using annual readings for the main water meter; at its simplest, this could be based on water bills, provided they are based on actual rather than estimated readings. This is recommended as core BPE and described here
- for more in-depth studies, including an analysis of the breakdown into uses, patterns of consumption across the week and in different seasons etc; this is likely to require the installation of bespoke metering and monitoring equipment – see > detailed BPE ***water monitoring*** in section 5.9.

There are privacy and ethics implications to using this data and care should be taken to ensure appropriate permissions are sought and GDPR complied with - see ethics and privacy in ***section 1.4***.

Specific considerations in timber construction:

None

4.12.2 Guidance and application – design stage

n/a as this technique applies at the in-use stage, but see > Core BPE ***Design Review*** for design considerations to facilitate in-use BPE.

4.12.3 Guidance and application – in construction

n/a as this technique applies at the in-use stage, but it is essential that water meters are calibrated and commissioned, as reliability of data will otherwise be compromised – see > Core BPE ***Commissioning***.

4.12.4 Guidance and application – completion and handover

It is essential that installed water meters and any associated logging systems are calibrated and commissioned, as reliability of data will otherwise be compromised - see > Core BPE ***Design review*** > ***Commissioning for considerations at completion***.

Following completion, the first year of occupation should be used to make sure that things are in place for the 2nd year energy audit i.e. meters are commissioned, a check has been done that they are reconciled (i.e. they add up) if there are sub-meters, a sense check has been carried out on the readings and the logged data (e.g. it is not uncommon for periods of missing data), and permissions are in place to access and use the data. This will ensure that the actual water audit is based on available and reliable data.

4.12.5 Guidance and application – in use

The initial water audit requires gathering of annual water consumption data, covering at least one full year of occupation. All new homes should be fitted with a water meter. It is useful to check whether residents are aware of it and of their consumption, and whether they are billed on a fixed charge or according to consumption; the latter would be good practice, to encourage good behaviour (although it usually does not make a significant difference on bills, as a large proportion of cost is a standing charge).

Ideally the audit would exclude the first year, when users are "settling in" and learning to operate the building, and some systems may still be getting fine-tuned – see previous section on recommendations in the 1st year, to put things in place for the audit.

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It is unlikely in most homes that sub-metering per end uses will be in place unless specifically requested at the start for BPE purposes.

What to do with the results?

Care should be taken not to draw excessive conclusions from the initial audit, particularly in the case of a single home or small sample of dwellings. Water consumption is closely related to occupancy patterns and behaviours (density, lifestyles patterns such as washing habits, stay-at-home vs out-working-all-day etc), rather than the building performance itself.

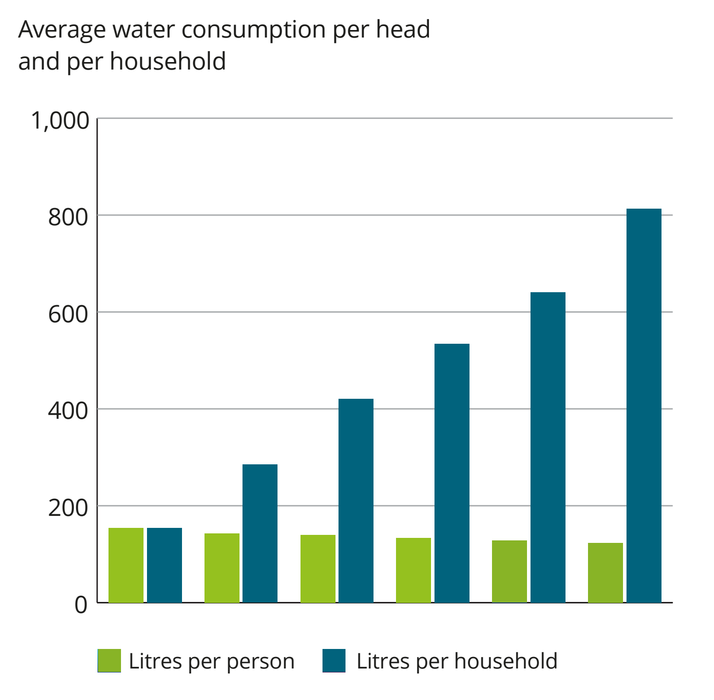
The annual water use can be related to performance metrics (typically, m^3/person/yr or l/person/day). If at all possible, this should separately identify:

- water consumption for external uses (e.g. gardening), if drawn from the mains
- contribution from water recycling systems (to internal or external uses), if any are installed. In the case of simple garden butts, this can just be noted by the BPE team, without quantification. In the case of more complex systems, or communal ones, the BPE team should consider installing temporary meters if none are already in place.

The following graph illustrates the average consumption of households in the UK, and how dependent it is on the number of occupants.

Water consumption in homes in the UK: the average is 142 litres per person / day; water consumption per household is heavily dependent on the number of occupants

Source: Energy Saving Trust, At Home with Water, 2013



Alongside benchmarking, results should be put into context, including patterns of use, efficiency of the water appliances (as established from the site visit and design review), and correlation with findings from the other BPE techniques – see following page.

The bathroom, followed by the kitchen, are the largest water users and the bathroom is where the largest savings are usually to be found, according to the Energy Saving Trust (2013 – see references). In large part, this relates to the flow rate of showerheads, the use of showers instead of baths, and the length of showers. Questions may be asked of occupants about their habits, but care must be taken as this can be considered private or sensitive. A core BPE exercise would typically be limited to observations such as the number of occupants, which is the strongest correlator to water use per household – see illustrations above.

Breaking down water consumption into end uses is typically not carried out in a core BPE study, as it requires a detailed review of appliances and fittings, sub-metering, and ideally an understanding of the residents' habits – see detailed BPE technique ***Water monitoring and analysis***, in section 5.9.

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Taking the weather into account

The weather may have some influence on water consumption, as some people will take more showers on hot days, but this will depend across people. A large study a few years ago showed no clear pattern in hot water consumption over the year, other than a summer reduction which was likely due to people being away on holidays (Energy Saving Trust, 2008).

It is important to look at weather data in the case of rainwater recycling systems, so that a rough estimate of their contribution can be carried out and compared with actual performance.

Looking at patterns

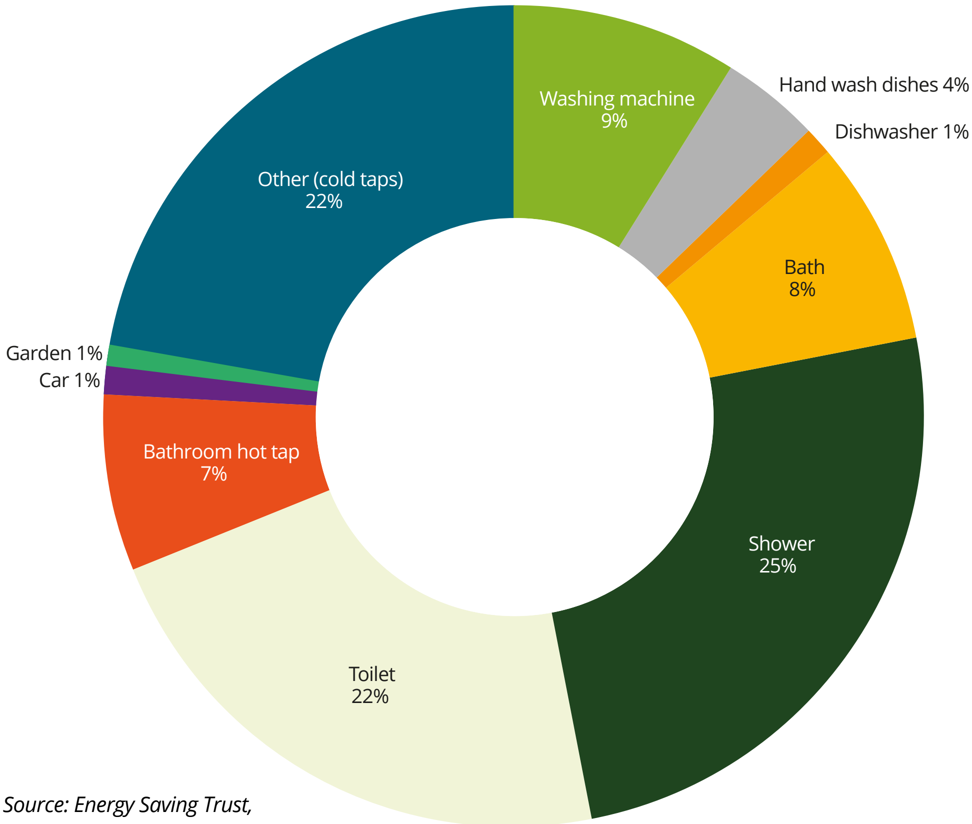
If possible through smart meters or access to regular readings, it can useful to look at patterns of consumption such as:

- Weekday / weekend
- Summer / winter e.g. people may take more showers in the summer, and use more for watering plants; on the other hand, they may be away for holidays
- Occupied / un-occupied: continuous consumption at night or when people are known to be away, would indicate a leak.

Correlation with other BPE findings

Findings from the water audit should be examined alongside those from the other BPE techniques, so that water performance is looked at holistically taking account of fittings and appliances, and occupant feedback and behaviours. Relevant BPE techniques include:

- Commissioning of water meters and hot water systems
- Site visit and design review: installation of water-efficient fittings and appliances, including any installed or changed by residents compared to the original design or as-built stage
- Energy audit: check energy use (total or, if sub-metered, that for hot water) alongside water consumption: the illustration below shows that a large part of water consumption also has energy implications
- Feedback from inhabitants: Occupancy patterns and habits e.g. working from home or stay at home with children would increase water consumption; do they take baths, or just showers?; feedback their fittings and appliances e.g. they may have replaced poor quality low-flow fittings for higher-flow ones.



Typical breakdown of water consumption in UK homes: this shows a strong correlation with energy consumption, as 44% is hot water (showers, baths, and hot water taps in bathroom and kitchen); an additional 10% is for dishwashers and washing machines, which would be linked to electricity use.

Source: Energy Saving Trust, At Home with Water, 2013

Next BPE steps
Where water consumption is well above design stage targets and/or good practice, and if this does not seem to be explained by obvious occupancy patterns, more detailed investigation is recommended to identify the likely causes e.g:

- Re-commissioning of water meters and hot water systems
- Sub-metering of water use to identify largest uses and possible leaks; this could be carried out alongside energy sub-metering of energy use for hot water
- Detailed occupancy studies.

See > Detailed BPE - ***water monitoring*** in section 5.9.

4.12.6 How to make it happen: who to do it, equipment, cost and time implications

This is a low cost technique in terms of equipment, even if temporary meters are installed for, say, sub-metering of recycling systems. The preparation phase will require some time to make sure data will be available, reliable and meaningful.

It can be carried out by any design professional, but some experience in BPE is recommended in order to analyse the results, correlate them with other findings, and not over-interpret.

4.12.7 Regulatory requirements

None

4.12.8 References and Further Information

Housing Fit for Purpose by Fionn Stevenson, 2019 (RIBA Publishing)

Energy Saving Trust, At home with water, 2013
www.energysavingtrust.org.uk/sites/default/files/reports/AtHomewithWater%287%29.pdf.

GUIDANCE ON CORE BPE TECHNIQUES

4.13 USER FEEDBACK SURVEYS

4.13.1 Overview of the technique

An essential part of BPE is to gather and analyse feedback on how homes perform for inhabitants and other users (e.g. FM team, building management team), from a functional, comfort, and general satisfaction point of view.

Very valuable observations and user feedback can be gathered from a site visit (see > ***Site visit – In use*** section 4.7.5 and > Core BPE ***Technique One Pager*** – Site visit in use) but feedback must also be gathered from the inhabitants themselves, and in a systematic manner. A range of methods are available; the core BPE exercise is recommended to use surveys (ideally standardised), which in a detailed BPE can be followed by detailed interviews, focus groups and ethnographic studies. Findings from these methods give context, depth and explanations to those from the other BPE techniques, including IEQ measurements, operation of the building systems etc, and they should be used alongside.

There are privacy and ethics implications to using this data and care should be taken to ensure appropriate permissions are sought and GDPR complied with - see > ***ethics and privacy*** section 1.4 at the start of this guide.

Specific considerations for timber construction

We have a natural affinity to nature (sometimes called biophilia) and the use of natural materials tends to have positive associations with our mood and wellbeing. This is the case with timber, and may transpire in how satisfied residents in timber constructed homes are (particularly if the timber is visible e.g. in cladding or exposed beams).

Other more project-specific issues may be identified during the design and construction stages or through the occupant surveys, for example in relation to moisture movement, air-tightness or IEQ – see relevant chapters on this issue.

Material	**Perception**					
	Creates a natural look & feel	Creates a warm & cosy environment	Visually appealing	Feels nice to touch	Environmentally friendly	Relatively cheap
Wood	93	92	88	87	68	31
Brick	61	62	58	30	47	30
Concrete	25	23	24	20	27	35
Steel	20	16	36	36	28	20
Aluminium	17	15	33	34	30	36
Plastic	14	18	24	36	14	71

The use of natural materials, and in particular timber, is usually associated with positive feelings

Source: Planet Ark survey on 1,003 Australians aged 14-64 years old, 2014; quoted in Planet Ark, Housing, Health and Humanity, 2015
https://makeitwood.org/documents/doc-1253-wood--housing--health--humanity-report-2015-03-00-final.pdf

4.13.2 Guidance and application – design stage

n/a as this technique applies at the in-use stage, but see > Core BPE ***Design Review*** for considerations at the design stage: users must be taken into account in the design, and involved if at all possible. This should also include incorporating relevant past BPE lessons.

4.13.3 Guidance and application – in construction

n/a as this technique applies at the in-use stage, but as construction progresses it is recommended to start putting in place arrangements for the post-occupancy activities e.g. appointments, contacting future inhabitants etc - see ***Chapter 2*** on overall set-up, and ***Chapter 4*** on stage-by-stage activities.

4.13.4 Guidance and application – completion and handover

Following completion, the first year of occupation should be used to make sure that things are in place for the surveys during the 2nd year, including making sure that inhabitants are happy to be involved, agreeing the best way to do so (e.g. in person, online) and rough dates for doing so (ideally with one survey in the summer and another in the winter), and ensuring that privacy and ethics have been respected – see > ***Section 1.4***.

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These early communications can also help to get a feel for any issues that may affect level of engagement with the BPE exercise (e.g. unresolved defects, dissatisfaction with the builder or developer etc).

In order to respect the time of residents and avoid building up fatigue, it is useful to coordinate the BPE exercise with other activities which require their time and input. This can particularly be the case on innovative or high profile schemes which involve a lot of research interest.

4.13.5 Guidance and application – in use

Surveys should be carried out after a year or two of occupation, after the "settling in" period.

One important consideration is that people tend to remember the extremes of their experience; if at all possible, the surveys should therefore be carried out both in summer and winter, to capture a more accurate representation of their experience on comfort and general indoor environmental quality.

User surveys e.g. Building Use Studies (BUS) surveys, or similar

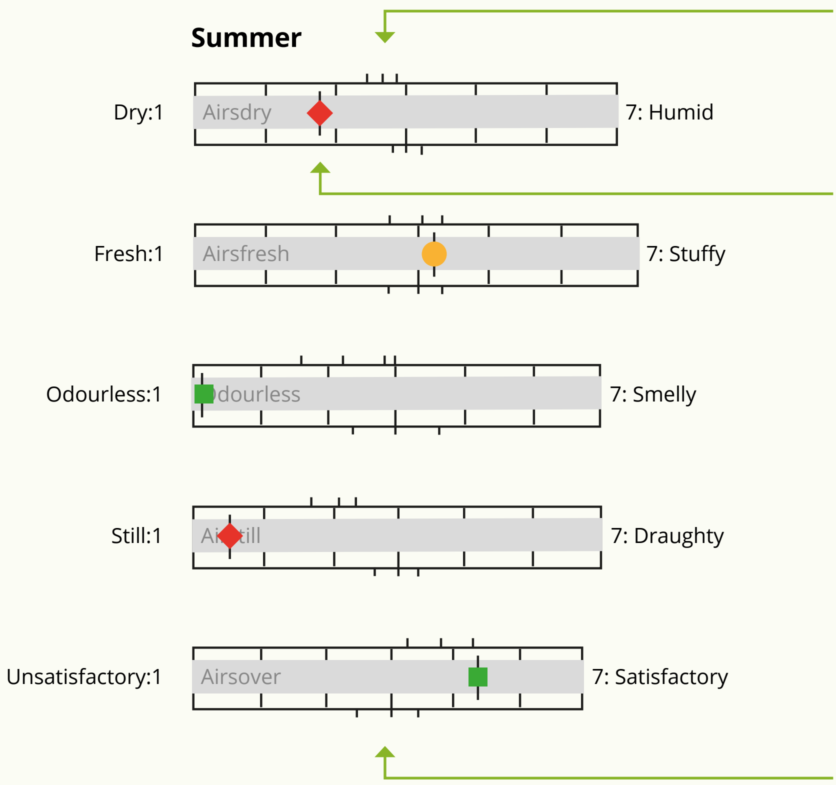
A survey of inhabitants on the performance of their home should be carried out, using Building Use Studies (BUS) questionnaires or similar. Where applicable, this should also include other users, such as the FM teams and building manager.

The questionnaires should not be more than 2-3 pages long and take more than 15 minutes to complete. They can be administered through a range of methods: interview pro-formas (especially for those who may have difficulty filling them in); standard write-in questionnaires; as the basis for a telephone interview; or online. The choice of any or all of these depends on circumstances.

While it may be tempting to tailor questionnaires, standardised surveys are very useful in several aspects:

- they have been developed over large numbers of projects, improving as lessons were gathered on which questions to ask and how to ask them in order to cover a comprehensive scope while not overwhelming inhabitants with too many questions, to ensure clarity, and to avoid biased and leading questions
- they allow results to be benchmarked against other similar projects: this is really useful since, for all schemes, it will be impossible to satisfy all people on all aspects, so a comparison can give a sense of how important an issue may be.
- They may have already been translated into Welsh or other languages (were required/helpful); for example, the BUS survey is available in Welsh.

Illustration of BUS results in one category (air in summer), including benchmarking and how to make use of it.



The 3 markers above the line represent the median and a confidence range for responses received to this question, across similar buildings: they are essentially the benchmark for that question

The coloured marker in the middle is the average score for that question, across all respondents in the survey, for the building being studied.

For example, in this case:

Top graph: building users found the building air much too dry: the score is below average (bottom markers), and even much lower than what is usually found in similar buildings (top markers).

2nd top graph: they found the air very slightly on the stuffy side, but almost neutral and very much within typical findings in similar buildings.

Bottom graph: they found the air overall satisfactory, and marginally better than in similar buildings

The 3 markers underneath the line are the scale mean and a confidence range: the mean is always the same against all question; the range varies a little

Source: example report, freely available from the Usable Buildings Trust www.usablebuildings.co.uk

If a BPE or project team is keen to explore topics not covered in standard questionnaires, it is recommended that this be added to a standardised one (rather than replacing it together); for example, housing associations or housebuilders may already have in-house questions which they want to ask their residents or customer. In that case it is useful to get advice on the wording of the questions from an experienced BPE professional, to ensure the questions are clear and unbiased; testing them with a small sample first is also useful to tweak the wording and remove any ambiguity or technical jargon.

Topics to cover

In the BUS methodology, once the surveys are completed, the responses are input in an excel spreadsheet and sent for external processing: this helps ensure consistency and rigour in the results.

The BUS surveys cover a range of topics on inhabitants' experience of their homes, including the following; should the team use bespoke surveys, it is recommended that they should cover at least the same topics in order to provide a robust and holistic view of building performance:

- Background information about age, sex and other basic information about the respondents and their lifestyles e.g. typical number of hours at home
- Overall satisfaction with the home
- Site context, design, needs, image, storage etc
- Perceived health
- Thermal comfort in summer and winter
- Ventilation and perceived air quality in summer and winter
- Lighting
- Controls – lighting, heating, ventilation..
- Ease of use of systems and their controls, and the information provided e.g. handover, Building User Guide.

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Air quality		Dissatisfied	-3	-2	-1	0	+1	+2	+3	Satisfied	n/a	?
How satisfied are you with the air quality...	in your home?		☐	☐	☐	☐	☐	☐	☐		☐	☐
	in your local area?		☐	☐	☐	☐	☐	☐	☐		☐	☐
How satisfied are you with air movement within your home during...	winter?		☐	☐	☐	☐	☐	☐	☐		☐	☐
	summer?		☐	☐	☐	☐	☐	☐	☐		☐	☐
How satisfied are you with odours within your home during...	winter?		☐	☐	☐	☐	☐	☐	☐		☐	☐
	summer?		☐	☐	☐	☐	☐	☐	☐		☐	☐

Controls			-3	-2	-1	0	+1	+2	+3		n/a	?
How satisfied are you with the user guidance provided for your home?		Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	☐	☐
How easy is it to use your controls for...	lighting?	Difficult	☐	☐	☐	☐	☐	☐	☐	Easy	☐	☐
	hot water?	Difficult	☐	☐	☐	☐	☐	☐	☐	Easy	☐	☐
	heating?	Difficult	☐	☐	☐	☐	☐	☐	☐	Easy	☐	☐
	cooling?	Difficult	☐	☐	☐	☐	☐	☐	☐	Easy	☐	☐

Design, space and layout		Dissatisfied	-3	-2	-1	0	+1	+2	+3	Satisfied	n/a	?
How satisfied are you with the...	appearance of the building?		☐	☐	☐	☐	☐	☐	☐		☐	☐
	the view to the outside?		☐	☐	☐	☐	☐	☐	☐		☐	☐
	cleanliness of common areas?		☐	☐	☐	☐	☐	☐	☐		☐	☐
	size of your home?		☐	☐	☐	☐	☐	☐	☐		☐	☐
	internal layout of your home?		☐	☐	☐	☐	☐	☐	☐		☐	☐
	amount of storage in your home?		☐	☐	☐	☐	☐	☐	☐		☐	☐
	size of private spaces (e.g. balcony)?		☐	☐	☐	☐	☐	☐	☐		☐	☐

Illustration: snapshot from a questionnaire produced by the Greater London Authority for the evaluation of the Old Oak and Park Royal scheme; the themes and wording of these questions is very similar to that of BUS surveys, although it includes additional questions. Importantly however, the BUS typically uses more neutral language: "how do you rate ... ?" rather than "how satisfied are you ... ?"

Source: www.london.gov.uk/sites/default/files/39._post_occupancy_evaluation_survey.pdf

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All homes should be surveyed; ideally all inhabitants would answer individually, but single surveys per household are common. The BPE should aim for a return rate of at least 20% in large developments (over 500 homes) but a much higher rate in smaller schemes: with determination, skill and experience, rates over 50%, and even up to 100%, are possible. Surveys with fewer than 100 responses are not statistically significant but are still very valuable in qualitatively identifying issues.

What to do with the results?

Care is needed when interpreting results, in order to take contextual factors into account. The size of the sample should also be considered: below 30-50 homes, the overall results can be heavily influenced by a small number of homes; it does not mean they are not important for these individual residents, but they may not be representative of the scheme overall.

The analysis must include looking at results alongside other BPE findings, including site observations, IEQ spot checks, energy and water use audits etc. It is important to give weight to feedback from inhabitants: too often, results are dismissed as people not using a building properly; instead, the mind-set should be to understand why buildings and systems are not performing as intended, and how they could work better for their intended user.

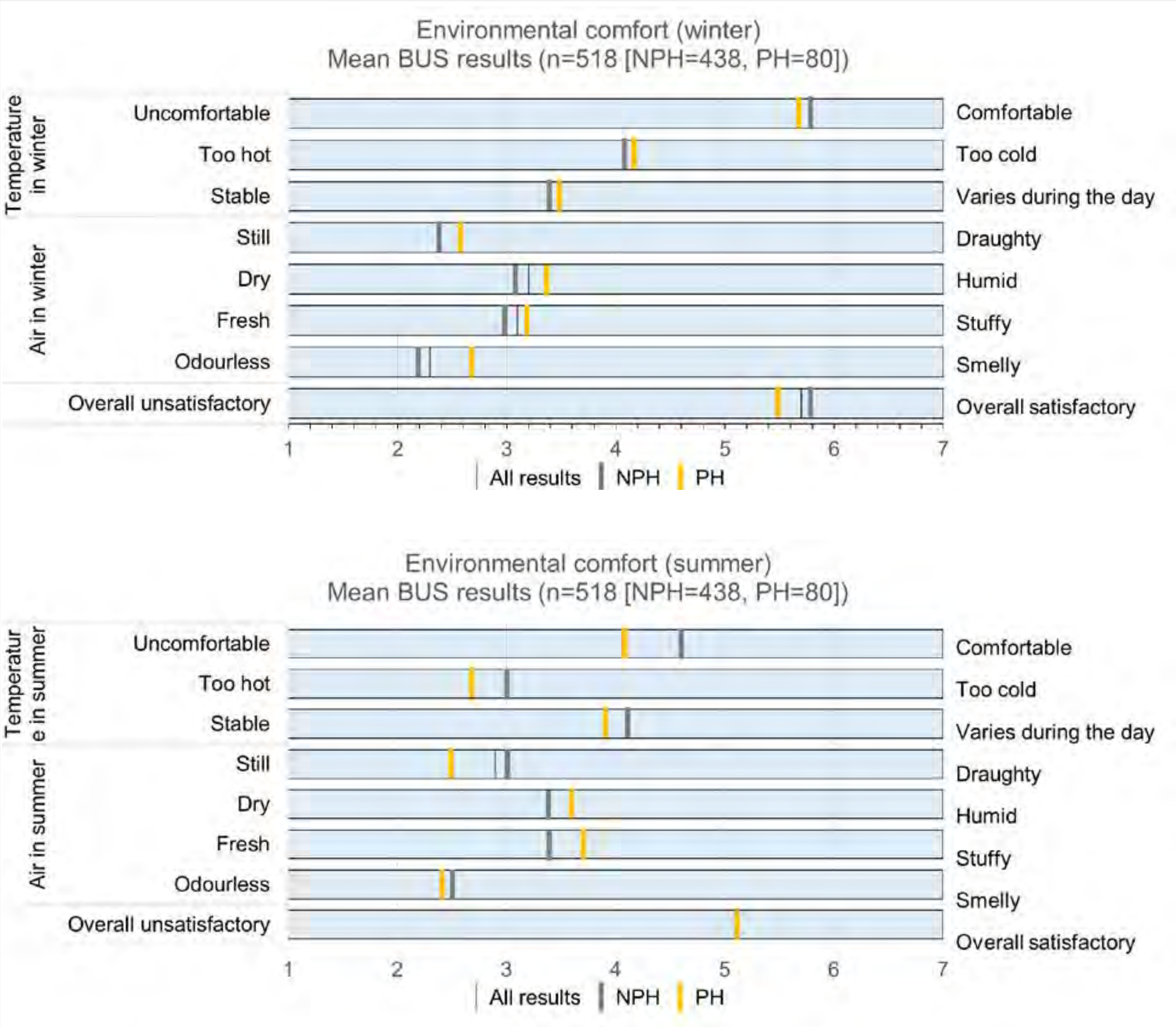
On schemes of several dwellings, it can be very useful to look both at average feedback across the scheme, the distribution, and, if possible, the outliers who may point at some explanations of what may be working well, or not at all.

The results analysis should include both the quantitative scores and the additional comments, which often include invaluable clues, notes on things not working well, features which are liked by residents etc.

Contextual information may also have been provided in the site visits and informal interviews; for example, personal (and sometimes sensitive) information about health is often very helpful in contextualising data. In this case, the BPE team must be clear when liaising with residents about the grounds for seeking information, how it will be used etc. see > section 1.4 on ***ethics and privacy***.

If standard surveys such as BUS are used, user feedback can be compared to benchmarks, which is very useful as it is impossible to satisfy everyone on all parameters – see illustration of BUS results and benchmarking in earlier sections. This can be done at different levels, all useful: globally, and separately for “user comfort” and “user satisfaction”, and down to individual issues (e.g. summer comfort, storage space etc). Attention must be given to the additional comments provided, not only the scores, as this will provide context and nuggets of information which may hint at underlying reasons for good or bad performance.

Example of BUS feedback results on temperature and air quality over a large sample of homes:
438 non-Passivhaus and 80 Passivhaus homes. Top: in winter; Bottom: summer. Overall satisfaction with temperature in summer is much lower, which highlights the attention needed to reduce overheating risk – see > Core BPE ***Overheating analysis***. Overall satisfaction with air quality was acceptable, but with a tendency for dry air.



Looking at context and patterns

On larger sites, it may be possible to draw trends by looking at the wider context and at patterns of user feedback across different categories of homes and inhabitants, for example:

- families vs single occupants / couples. Homes may work better for one category than another
- different locations across the site e.g. more / less noisy, easier or closer access to green space and amenities etc
- tenure: on some sites, different tenures benefit from different building management arrangements, which can significantly affect overall conditions and the experience of inhabitants
- etc ...

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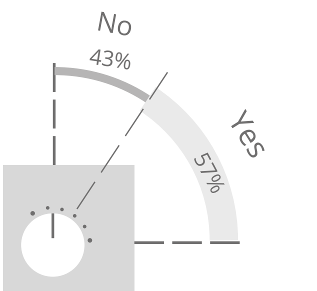
Residents comments
Residents were given the opportunity to comments on their balcony, with most commenting on the size or exposure



Do you find the heating and hot water easy to adjust?

Controls
Just over half of respondents felt their heating and hot water was easy to adjust. Notably, those who reported they had not received an instruction leaflet have also said that the heating and hot water were not easy to adjust.

Extracts from a post-occupancy evaluation report, which included resident feedback surveys: (top) the feedback on balconies could be really useful in the design of later schemes; (bottom): over 40% of residents do not find the heating and hot water easy to adjust, which is a design lesson for future schemes, highlights the importance of the user manual, and is a good example of survey finding that would be useful to examine alongside the energy and water use audits.

Source: Levitt Bernstein, Loudoun Road post occupancy evaluation report, 2019. Freely available at:
www.levittbernstein.co.uk/research-writing/loudoun-road-post-occupancy-evaluation/

Correlation with other BPE findings

Findings from the user surveys should be examined alongside those from the other BPE techniques, so that building performance is looked at holistically; user feedback can help explain findings from other BPE techniques, and inversely it may be explained by an issue uncovered elsewhere. E.g:

- user feedback on winter comfort, vs very low space heating consumption: this may indicate inhabitants worried about energy costs
- user feedback on poor quality water fittings or appliances (e.g. low shower rates), vs water consumption: if water consumption is still low, the BPE should note that this is not a positive finding overall, as inhabitants are dissatisfied; if it is high, it may be that inhabitants replaced some of the fittings (not uncommon)
- High electrical uses throughout vs observations and feedback from user surveys: is the home occupied for long hours and /or at relatively high density?
- User feedback on summer comfort vs design review and overheating analysis and vs spot-checks on the internal environment: people experience comfort differently, and thermal comfort is the result not only of air temperature but other facrors such as air movement, radiant comfort (= temperatures of surrounding surfaces), metabolism etc. it is useful to gain as complete a picture as possible in order to identify what may be the reason for discomfort e.g. poor window opening, concerns about security or safety which limits the operation of windows, heat gains from communal heating or excessive unshaded glazed areas etc.
- User feedback on air quality vs site observations (e.g. VOC smells? Polluted site?) and commissioning of ventilation (e.g. was the air flow rate adequate?)

Next steps

- implement "easy fix" remediation and improvements e.g. new or updated training sessions to inhabitants on how their systems work
- gather lessons for future projects.
- identify where detailed BPE on occupancy feedback may be required : see ***section 5.11***.

4.13.6 How to make it happen: who to do it, equipment, cost and time implications

BUS surveys (or equivalent) can be carried out by any professional, including project team members or individuals external to the team; however, and particularly if the surveys are not standardised, it is recommended that someone experienced in BPE should carry them out, or at least supervise them – both in terms of how to liaise with inhabitants, and in interpreting and communicating the results.

It can also be advantageous to involve academics, as they have experience in this activity and benefit from preferential rates to use BUS. In any case, using standardised surveys such as BUS provides a framework and a process which help ensure independence and robustness of the results, even if the feedback is gathered by individuals who were involved in the project itself.

The BPE team themselves would typically carry out the surveys, but the right to use BUS surveys, along with the forms themselves and the data processing, can be commissioned directly from Arup (who now run the scheme, after its development by the Usable Buildings Trust) or through one of their partner organisations (listed on BUS methodology website).

As for the other BPE techniques, if external individuals are in charge of the surveys, it is recommended that the project team should still remain involved, as they can provide valuable context, and as they are more likely to assimilate BPE lessons for their future projects than if it is seen as a separate exercise from their main day-to-day job.

4.13.7 Regulatory requirements

None

GUIDANCE ON CORE BPE TECHNIQUES

4.13.8 References and Further Information

Fionn Stevenson, Housing Fit for Purpose, 2019 (RIBA Publishing)

Building Use Studies (BUS) methodology: https://busmethodology.org.uk/

Usable Buildings Trust: www.usablebuildings.co.uk/ : this is an invaluable resource with many case studies and tips, developed over decades which led to the creation of BUS. It also includes the BPE reports from the Technology Strategy Board programme.

RIBA Post Occupancy Evaluation resources:
www.architecture.com/knowledge-and-resources/resources-landing-page/post-occupancy-evaluation

Building Performance Network, Rajat Gupta and Matt Gregg, State of the Nation review – Performance Evaluation of New Homes, 2020

SECTION

05

GUIDANCE ON DETAILED BPE TECHNIQUES

Photo by Matheus Potsclam Barro from Pexels

GUIDANCE ON DETAILED BPE TECHNIQUES

5 GUIDANCE ON DETAILED BPE TECHNIQUES

5.1 WEATHER STATION

For more detailed studies (diagnostic and forensic BPE), a weather station is essential to take account of the actual weather in the period monitored and of the microclimate around a home, measuring:

- air temperature
- wind speed and direction
- global and diffuse solar radiation
- relative humidity (RH)
- other parameters, depending on the site context and the objectives of the diagnosis study e.g. noise levels, pollutant levels (e.g. particulate matters).

Data should be logged on an hourly or half-hourly basis throughout the monitoring period. Suppliers can provide advice on locating weather stations, and retrieving logged data (also check logging capacity to ensure full duration will be recorded).

Data will sometimes need to be converted into a standard weather file format such as .epw, .tm2 etc depending on how it is intended to be used.

Weather stations can be hired or purchased, but should be well calibrated, located wisely and the logging facility tested in order to ensure that robust readings are reliably captured.

Example of portable weather station *(source: courtesy of Julie Waldron)*

Wind Speed Data Logger OMEGA

Grey Globe, Acrylic ball (Globe Temperature in the sun)

Solar radiation shield with Hobo Data Logger inside (Air Temperature and Relative Humidity

Hobo Data Logger (Light, Globe temperature in the sun and Globe temperature in the shadow)

Sign "Environmental Station"

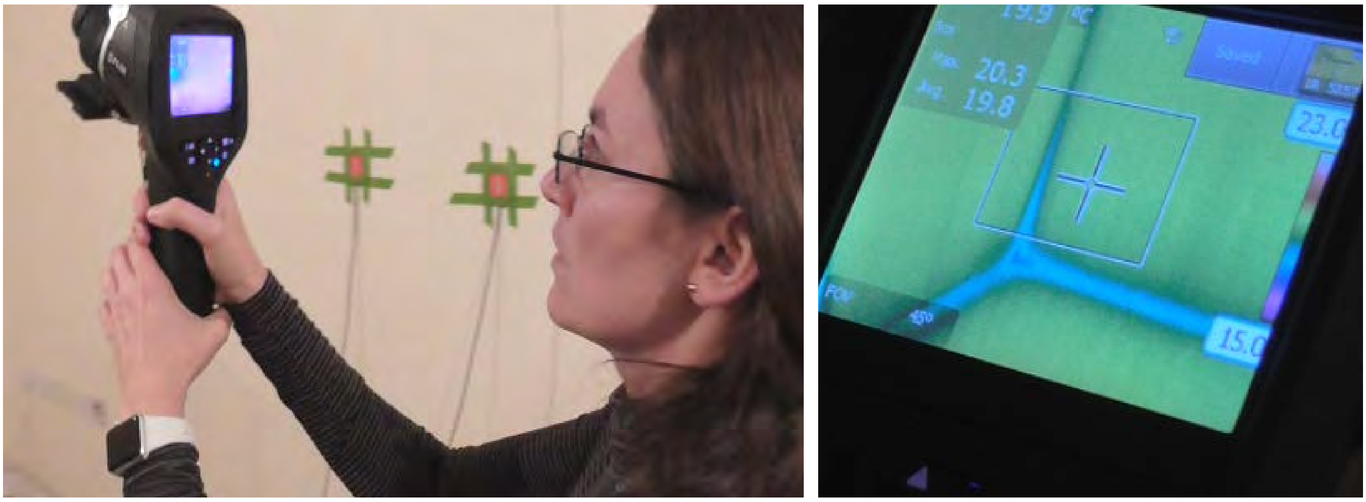
5.2 THERMOGRAPHY

5.2.1 Overview of the technique

Thermography is a non-destructive, non-contact technique for assessing the thermal performance of a building envelope. It uses a heat sensitive camera to detect gaps in the insulation, cold bridges in the building fabric, water infiltration or areas of high infiltration (draughts), all of which can compromise the energy efficiency by increasing the heat loss. It is best carried out by an experienced professional to do it properly and interpret results correctly, but spot checks may be carried out by more generalist people, as part of the core BPE exercised – see > ***spot checks*** section 5.2.6. It tends to be most useful when there are serious issues, rather than to the level requiring for achieving exemplar performance.

Carrying out and acting on the results of a thermographic study could have benefits both in terms of energy consumption and thermal comfort. Eliminating cold bridges can also have health benefits and reduce the risk of fabric degradation, by limiting the likelihood of condensation and of mould growth.

Thermographic cameras look very similar to regular cameras, but they detect long-infrared radiation rather than light. The amount of long-wave radiation emitted by an object increases with temperature, so these cameras produce a heat map of the image they capture with cooler objects or surfaces contrasting against warmer surfaces. Weak spots, gaps or thermal bridges in a building's insulation envelope will create cooler surfaces and therefore show up on the thermographic images.



Home Grown Homes - Pentland Close, Cardiff
Images taken when thermographic camera was used on this pilot BPE project
(Source: Sustainability in Energy and Buildings, Smart Innovation, Systems and Technologies 2019 vol.163)

Specific considerations for timber construction

None

5.2.2 Guidance and application – design stage

Thermography is not applicable pre-construction stage. See sections > ***4.6 and 4.8*** on how to design for reduced thermal bridging and good air tightness.

5.2.3 Guidance and application – in construction

Ideally a spot-check survey should be carried out once the building thermal envelope is complete, but whilst there is still scope to carry out any remedial action required if the survey identifies problems. It should take place in colder weather with the (permanent or temporary) heating on to ensure a significant contrast between internal and external temperatures. It is usually recommended that a building should be heated to at least 10°C above ambient temperatures for about 24 hours before thermal imaging commences. N.B. Homes constructed in heavier-weight masonry construction may take longer to achieve this temperature differential. The optimum timing is very early in the morning, before the sun is up and warming any external surfaces. Alternatively surveys can be scheduled for several hours after dark, or (less ideally) on very overcast days.

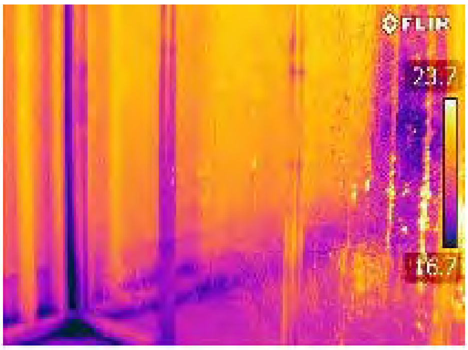
GUIDANCE ON DETAILED BPE TECHNIQUES

The Building Performance Network report "State of the nation review - Performance evaluation of new homes" (see references) reviewed thermographic surveys on 44 project sites. They concluded: "Thermal weakness at openings seems to be endemic across the sector as issues with doors and/or windows were identified in 84% of the project sites, demonstrating a need to improve detailing, specification and workmanship. "Junctions and joints" and "roof, eaves and loft space" are also highlighted as areas requiring attention, as thermal bridging issues were pinpointed in nearly half the project sites."

It is a good idea to carry out spot-checks with a thermographic camera during air tightness testing as the camera can help locate areas with higher rates of infiltration. Note the camera can't 'see' the cold air entering the building, but the cooling effect of the cold air on the surfaces it passes. This extra level of diagnosis can help identify sources of excess infiltration so that they can be fixed. – see > ***airtightness section***.

Home Grown Homes - Ffarm Moelyci: Image of thermography used during construction
(Source: Sustainability in Energy and Buildings, Smart Innovation, Systems and Technologies 2019 vol.163)

Digital image 1 illustrates the corner of one of the external walls which is North facing.



Thermogram 1 illustrates the overshadowing effect of the high reflective coating of the insulation

First floor apartment - Internal view of external wall, North Facade (Bedroom)

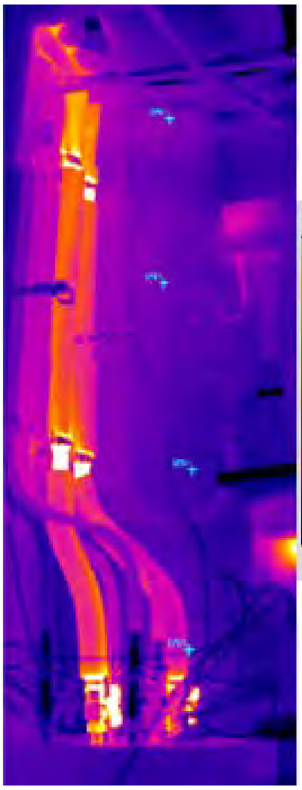
Digital image 2 junction detail

Thermogram 2 junction detail

First floor apartment - Internal view of external wall, West Facade. Ceiling to wall junction and window detail (Bedroom)

It is worthwhile doing a spot check on the building services at the same time as the survey of building fabric, if services are operating. Look for areas that show up particularly hot which may indicate poor or discontinued insulation to pipework or ductwork; this is especially useful where services are concealed.

GUIDANCE ON DETAILED BPE TECHNIQUES



Thermography showing significant heat loss from poorly insulated hot pipework - this can exacerbate overheating risk as well as poorer energy efficiency.

(Image courtesy of Mitch Swainson)

What to do with the results?

Diagnostic: If a thermography expert has been employed then a written report should be provided after the survey. According to BSRIA this report should include a statement of the survey objective and

- the date and time of survey
- environmental conditions prevailing at the time of the survey, such as
- wind speed/direction, internal and external temperature
- the infrared technology used
- the site-specific survey methodology
- infrared thermograms with temperature calibration
- photographs of thermogram locations
- an interpretation of the thermograms
- the conclusions/recommendations drawn from the survey.

Links to more detailed BPE:

Thermography might help pick up a wide variety of building performance issues, including sections of facade, corners or details that appear to be losing more heat than their surroundings. Cross checking these issues with the findings from other BPE techniques can help diagnose why this additional heat loss might be occurring:

- Thermal bridging analysis – > ***detailed BPE***
- Hygrothermal analysis e.g. Wufi – > ***detailed BPE***
- Airtightness review and testing – > ***core BPE***
- U-value calculations identified in the > ***energy strategy review*** – see core BPE, and as-built U-value measurements, if any.

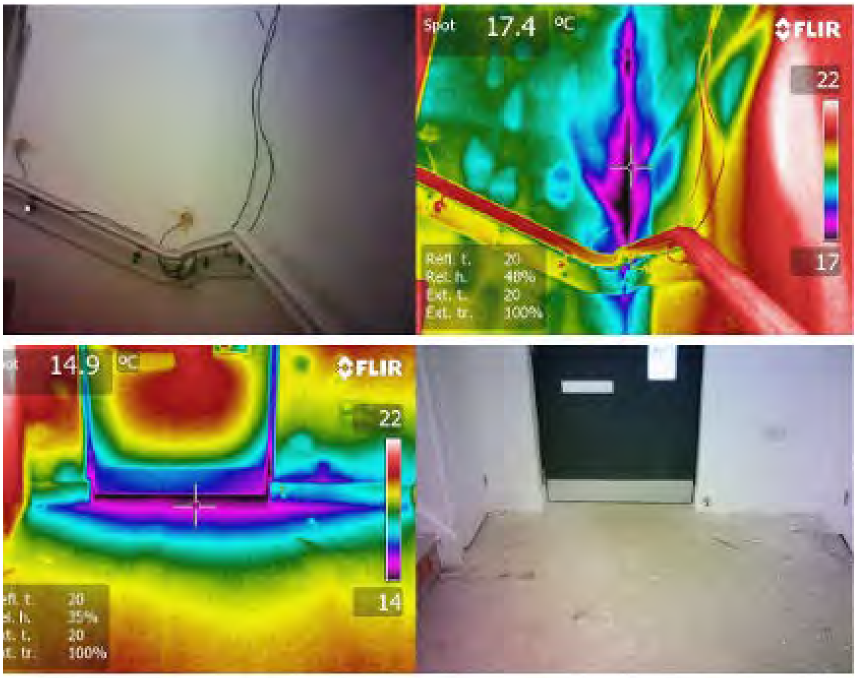
5.2.4 Guidance and application – completion and handover

As per construction stage.

5.2.5 Guidance and application – in use

Thermography can be valuable to help diagnose issues that develop post occupancy. The technique is non-invasive and relatively quick, so minimal disruption is required. While it is useful to carry it out from inside as well as outside, it is still possible to do it only from the outside if that is preferred by residents. It can be correlated with site observations and user feedback e.g. condensation and, in severe and sustained cases, become apparent through mould growth - see guidance on in-use analysis "***Making sense of it all***" in section 3.5. **Note these observations would not capture interstitial condensation, which can be as much if not more of a threat to fabric and structure.**

GUIDANCE ON DETAILED BPE TECHNIQUES



Internal thermal images - *Source: BPN State of the Nation report, 2020*

5.2.6 Doing it lightly – spot checks

As part of the core BPE, the team may find it useful to buy or rent a thermographic camera and use it to explore the external and internal building fabric during construction, ideally when pressure tests are taking place. Areas with high contrast surfaces may indicate higher heat loss; they can then be explored as they may be sites of air leakage or of thermal bridging.

Keep a record of the survey with notes on the date, weather that day, where each thermograph was taken and what it may be indicating.

NB more subtle issues may not show up using this core check, but the camera should make it easier to locate significant issues while it is relatively easy to fix them.

5.2.7 How to make it happen: who to do it, equipment, cost and time implications

Core: thermography spot-checks - It is recommended to allow half a day to survey one or two homes for any obvious heat loss issues, with a further half day to analyse the results and provide a report.

Diagnostic – expert thermographer - The survey should follow BS EN 13187:1999 Thermal performance of buildings (see references). The UK Thermography Association recommends that survey reports are completed by personnel who have completed appropriate thermography training. The International Standard, ISO 18436 part 7 sets out requirements for certification of thermographers at three levels, referred to as Categories in the Standard.

In the UK Certification of thermographers is managed by PCN, part of the British Institute of Non-Destructive Testing (BINDT). The UK Thermography Association (UKTA) is also part of this Institute and provides a list of its members with a map of their locations on its website at www.ukta.org.

BSRIA advise clients to ask for and look at examples of similar work done by the same thermographer. A competent building thermographer will almost always ask lots of questions, drilling down into what is required and then suggesting and explaining methods required to achieve it. Clients should expect this and ask plenty of questions themselves.

Home grown Homes: Thermographic camera used for pilot BPE studies
(courtesy of Diana Waldron)

Prices for thermographic cameras range from £150 to several thousands, with a consequent range of quality and specification. Cheaper models tend to display fewer pixels (60x60 pixels) making it harder to see definition within the images, and have a lower refresh rate (which may be less of a problem when taking images of still buildings). Higher specification models display more pixels (640x480 pixels) and have greater thermal sensitivity (down to 35mK).

5.2.8 Regulatory requirements

Building Regulations Part C require continuity of insulation and limiting thermal bridging, but has no specific requirement for checking this at completion, for example through thermography.

5.2.9 References and Further Information

BS EN 13187:1999 Thermal performance of buildings. Qualitative detection of thermal irregularities in building envelopes. Infrared method - https://shop.bsigroup.com/en/ProductDetail/?pid=000000000001569434&_ga=2.211800732.841438609.1581084229-1665240812.1578396386 (costs £130)
www.bindt.org/admin/Downloads/Building%20Thermography_UKTA.pdf

BSRIA - Thermal Imaging of Building Fabric (Colin Pearson) 2011
www.bsria.com/uk/compliance/airtightness/guidance-to-download/ (free to download with registration for a BSRIA account)
www.flirmedia.com/MMC/THG/Brochures/T820325/T820325_EN.pdf THERMAL IMAGING GUIDEBOOK FOR BUILDING and renewable energy APPLICATIONS - lots of helpful example images and applications for thermographic cameras in buildings

Building Performance Network State of the nation review - Performance evaluation of new homes, June 2020: https://building-performance.network/research/state-of-the-nation-domestic-buildings

Littlewood, J.R. Waldron, D. Newman, G. Hedges, D. Zaccaro, F. 2019. Building Performance Assessment Protocol for Timber Dwellings, Conducting Thermography Tests on Live Construction sites. Chapter 62. In: Smart Innovation, Systems and Technologies, Vol 163: https://link.springer.com/book/10.1007/978-981-32-9868-2, pp. 735-745: https://link.springer.com/chapter/10.1007/978-981-32-9868-2_62.

GUIDANCE ON DETAILED BPE TECHNIQUES

5.3 IEQ TESTING AND MONITORING

5.3.1 Overview of the technique

Monitoring indoor environmental quality (IEQ) within homes as they are occupied can provide valuable feedback in a number of ways, especially to verify and quantify the extent of a problem raised by occupants or uncovered through an initial design review or site observations. In the case of air quality, it can help identify causes and solutions, as complaints from occupants are usually, on their own, too generic. The most useful studies combine internal monitoring with energy consumption, occupant feedback and external weather data to give a more comprehensive picture.

Temperature and humidity are the most common IEQ parameters monitored, and this can be done relatively easily and cheaply. They are essential factors to assess the performance of the homes, relate physical data to resident feedback on comfort and air quality, and can help identify the risk of issues such as condensation, mould growth and poor health due to under-heating or under-ventilation of homes.

Indoor air quality parameters are usually more expensive to monitor, but this may be justified in a detailed BPE exercise if there are causes for concern, particularly about the health of inhabitants e.g. particulate matters, formaldehyde, radon. Furthermore, developments in technologies have offered many new opportunities in recent years, and an initial BPE exercise should allow to narrow down the range of pollutants which would be useful to look into on a case-by-case basis.

Daylight measurements and monitoring are relatively rare and typically only in legal dispute or academic research context, and not covered here. In most situations it would be unlikely to bring much value compared to the core BPE exercise i.e. site visits and observations, a review of the design, and an analysis of feedback from inhabitants.

Acoustic testing and monitoring is very specialised, and not covered here: it should only follow an initial review by an acoustic specialist, and detailed advice from them on what is appropriate – in some cases, it may be sound levels, in others it may be acoustic testing of building elements themselves.

This section covers IEQ monitoring as part of a detailed BPE exercise. However, as part of a core BPE exercise the team may find it useful to carry out **spot checks and short-term monitoring**, as an initial indication and sense check against other BPE findings – see > ***section 5.3.6***.

Specific considerations for timber construction

Solid timber naturally emits volatile organic compounds (VOCs). In addition, wood products are often treated (e.g. preservatives, fire retardants, coating) or processed with glues and varnishes (e.g. glulam, plywood, MDF and other glued wood products). Some of which can emit a relatively high amount of VOCs. Some VOCs are not known to be harmful, but others are, especially formaldehyde.

Formaldehyde is a known carcinogen. A certain amount in a building is not abnormal in the first few weeks after completion, but concerns should be raised if levels do not significantly decrease after a few months of occupation. The smell is noticeable at high levels. Symptoms from exposure may include irritation of the eyes, nose and throat, together with sneezing, coughing, nausea (these are relatively non-specific and could be caused by a number of other reasons).

- Preservatives: according to TRADA, these usually only have a negligible effect on indoor air quality, as the compounds are encased within the timber itself
- Coatings, glues, varnishes etc: Low-emission labels are available and should be specified wherever possible. These should be part of the design and specifications review.

More information on standards, references, and the types of VOCs that may be emitted can be found in the TRADA information Sheet 0-14 Specifying timber for indoor air quality.

Wood products are by no means the only sources of VOCs in buildings: other materials and products are common sources, for example paints, glues, and varnishes; and products brought by residents, such as cleaning products and cosmetics.

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Sonaspray®fc cellulose acoustic ceiling spray finish (M1 class)

Water based emulsion (Natural Building technologies)

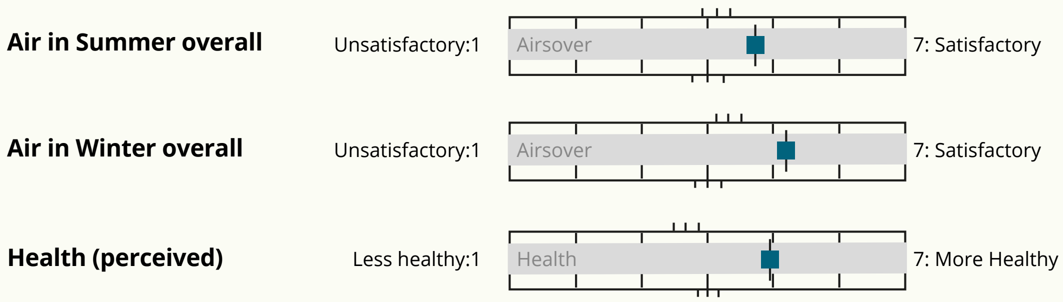
Earthborn Eggshell (Natural Building technologies)

Interior timber treatment:

Natural low-emitting Osmo finishes (Osmo Polyx Oil & Osmo Raw)

Eco alternative to fire retardant by Envirograf®

UEA Enterprise Centre, Archtype
Image credit Dennis Gilbert



Low-VOC materials should be specified, and buildings using timber products can report very good indoor air quality. This is the case for example of the Enterprise Centre at the University of East Anglia, which took a careful approach to specifying low-emissions products and reports good feedback from occupants on perceived air quality and health.
Source: Chryssa Thoua, Architype, presentation at 2018 Passivhaus event)

5.3.2 Guidance and application – design stage

n/a as this technique applies at the in-use stage, but see Core BPE > ***design review*** for design considerations to facilitate in-use BPE as it is useful to consider at the design stage what aspects of the homes IEQ performance might be validated/verified by a monitoring project.

The following advice on locating temperature sensors should be followed; this will be useful both in terms of reliability of the data, and if the sensors are linked to controls on the heating (and cooling, if present) systems:

- Do not install the temperature sensor near hear or cooling sources i.e. radiators and other heating devices, cooling systems of any kind, and appliances that consume a significant amount of power or output heat such as ovens, fridges, dishwashers.

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- The temperature sensor should not be exposed to direct sun, and ideally it should be installed away from windows, ventilation units or any excess air movement.
- The installation of sensors on the inside of an outside wall might have a negative impact on the temperature measurement.
- Make sure there is no pipe work in the wall behind the sensor.
- Temperature sensing, particularly in rooms with convective heating such as radiators is best measured at or near head height, so around 1500 to 2000 ffl (finished floor level).

5.3.3 Guidance and application – in construction

n/a as this technique applies at the in-use stage, but see Core BPE > ***site audits*** to ensure the design proposals are being implemented for good performance and to facilitate BPE in use.

See Core BPE > ***commissioning***: any sensors and logging equipment should be calibrated and commissioned, as reliability of data for the BPE will otherwise be compromised.

Some projects targeting very high levels of air quality may wish to monitor air quality during construction itself – in that case, refer to the section on spot checks; pollutants of particular interest at this stage would include dust, formaldehyde and other VOCs, and other products likely to be generated on site.

5.3.4 Guidance and application – completion and handover

Any installed IEQ sensors and monitoring equipment should be calibrated and commissioned, as reliability of data will otherwise be compromised - see Core BPE > ***commissioning for considerations at completion***. A sense check should be carried out on the readings (e.g. it is not uncommon for periods of missing data, or sensors in the wrong location could give misleading readings).

5.3.5 Guidance and application – in use

It is during occupancy that this technique can really be actioned.

Before any IEQ monitoring, the BPE team should agree access and terms with inhabitants, being mindful of their privacy and data protection – see > ***privacy and ethics***.

The BPE team should establish the appropriate scope of IEQ monitoring. This is not a routine exercise, so the scope should be informed by previous (core) BPE activities which pointed to potential issues requiring more investigations, or by a particular motivation of the project team or client (e.g. BPE for a pilot home or to test new products, or as part of academic or applied research).

Temperature and humidity

Temperature and humidity are the most common IEQ parameters to monitor; they can indicate a wide range of issues and are closely relate to comfort and, in severe cases health. Our perceptions of thermal comfort are closely linked to humidity as well as temperature, so it is useful to look at both together: cold temperatures at high humidity levels will feel much colder; and hot temperatures at high humidity levels will be much less comfortable, as it is then more difficult for our bodies to cool down through evaporation.

Sensors that combine both temperature and humidity are ideal and are relatively inexpensive to use for basic monitoring. Usually a number of them are used to monitor several rooms including kitchens, living rooms and bed-rooms – see design section for advice on location, to ensure they pick up a representative experience of the space.

The data loggers will sense temperature and/or humidity readings with a frequency (half hourly tends to be sufficient) that can usually be set prior to installing them. Simpler units will then need to be retrieved to download the data collected from them for processing. More sophisticated units can connect to local wifi and export the data collected that way allowing real time monitoring and removing the need to visit the homes to collect the data.

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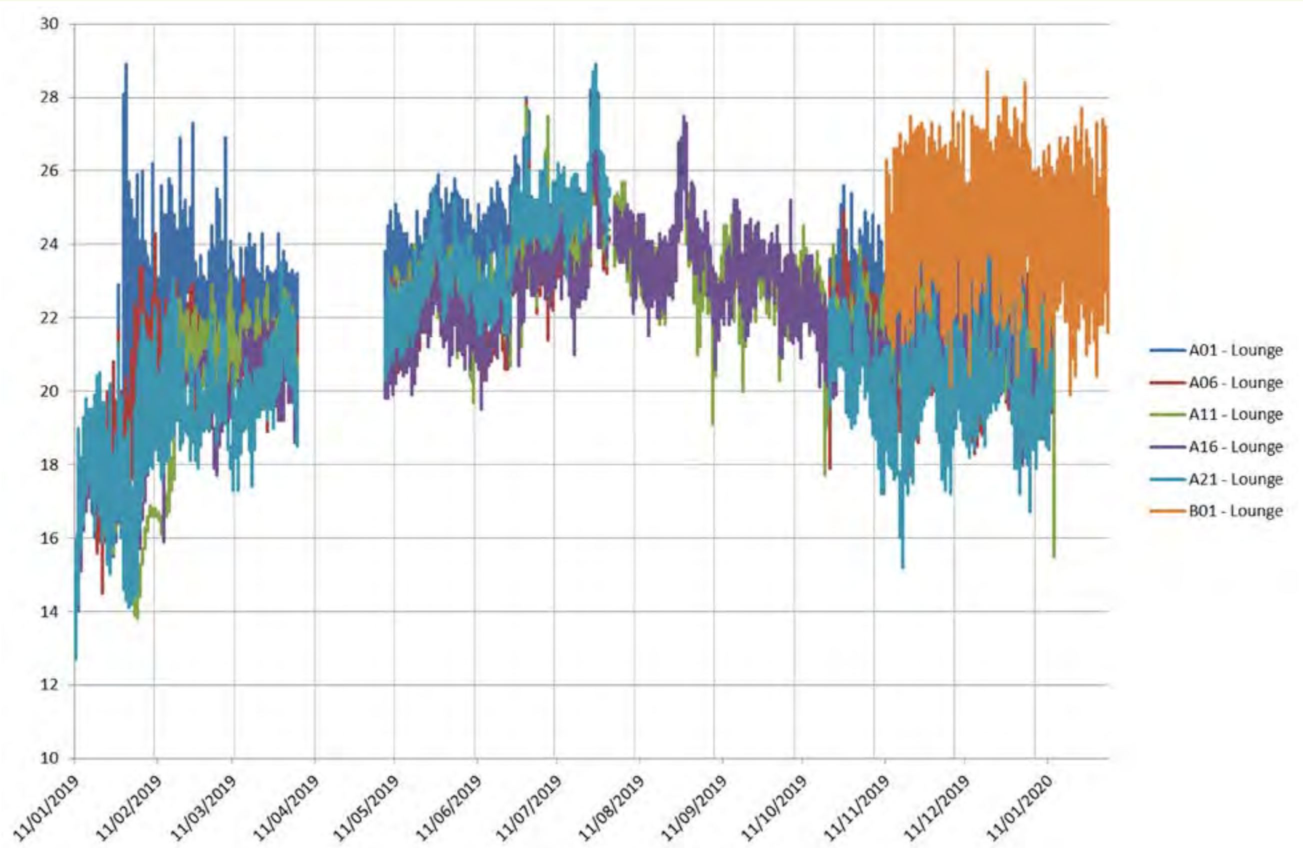

Example of indoor temperature monitoring: Monitored temperature data over one year, from a scheme in the south of England, comparing the living room temperatures recorded in 6 homes within the same development. There are some gaps in the data where loggers became full and there was a delay retrieving the data and resetting them. Data recorded in the early weeks is more volatile as they were not all inhabited until the end of March. Variations in temperature preferences can be seen – especially for unit 71 (orange) which only had data available for the end of the monitoring process. Inhabitants appear to enjoy warm internal temperatures (unless the sensor in this room is poorly calibrated).

Indoor air quality

Indoor air quality monitoring would be appropriate following a core BPE exercise where occupants feedback showed complaints of stuffiness or headaches, and the issues persisted after re-commissioning the ventilation system and checking that ventilation rates being delivered are adequate; the monitoring should check whether the following pollutants are present, and at which levels:

- Formaldehyde and other VOCs, or example if the rooms were freshly painted, or if the site visit notes a number of consumer products such as air fresheners, scented candles etc, or if the homes contain a high amount of timber products (especially processed ones). Formaldehyde is a common VOC in buildings, especially those of timber construction, and is also a known carcinogen, so it is worth considering sensors specifically calibrated to detect it, alongside ones for VOCs more widely. The initial VOC monitoring, with analysis of the spectrum, should indicate the most likely VOCs of concerns; this in itself should lead to possible reasons e.g. building materials, benzene from car exhausts, consumer products, cleaning products etc.
- Particulate matters, if there are combustion appliances such as indoor fires, candles, and gas cookers, or for locations on sites with high outdoor pollution. NOx are also relevant but more difficult and expensive to measure – typically, this would involve specialist equipment and measurements over a set period rather than continuous monitoring.

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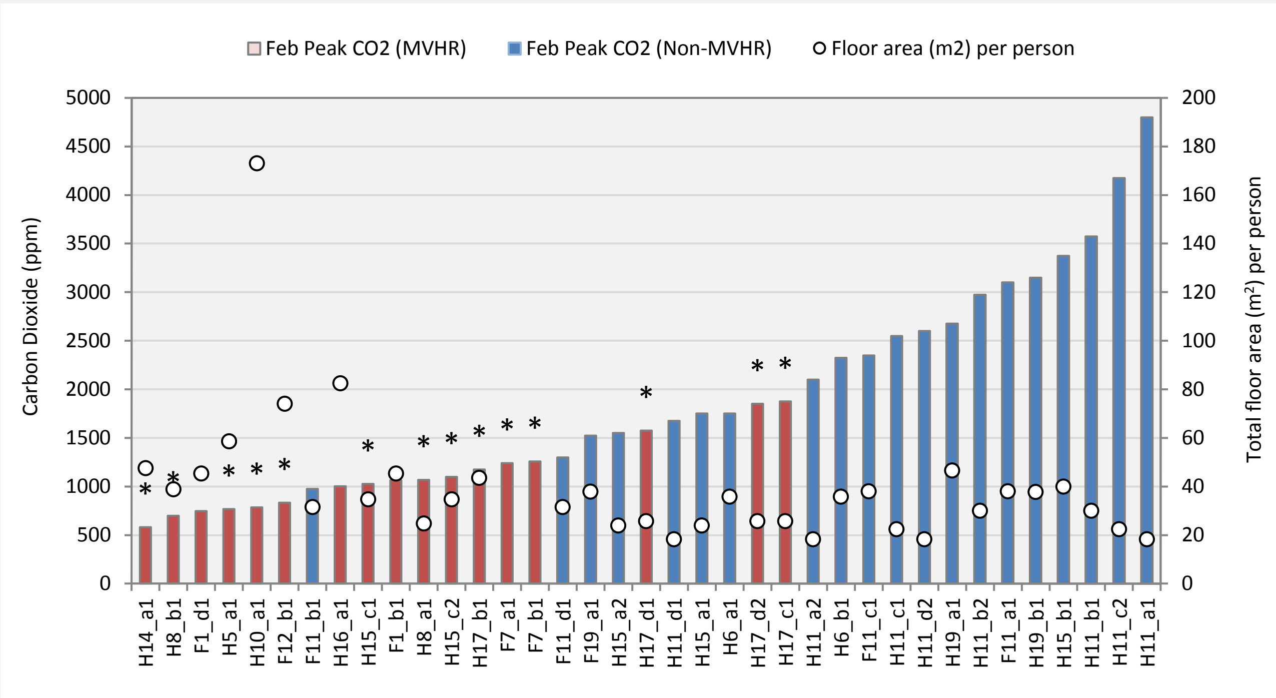
- If indoor air quality concerns are raised and there are combustion appliances, it would also always be safe to check carbon monoxide levels (even if there are CO detectors, as per law), particularly if occupants also report dizziness or nausea.
- Radon monitoring is recommended if the site is in a radon affected area; in some cases it will be required by law: see www.ukradon.org/information/ukmaps for advice on requirements, mitigation measures, and a map of affected areas (this is the case for large parts of Wales). Relatively cheap testing kits can be ordered and left to measure for a few months.
- CO_2 levels is often used as a proxy for ventilation effectiveness, but is less relevant in homes than in densely occupied non-domestic spaces such as offices. In homes, as first step it is recommended to measure the air flow rate from the ventilation systems as part of the core BPE exercise, and to take humidity levels (as spot checks or for longer periods): humidity is more closely linked to domestic occupancy patterns, it is also influenced by the effectiveness of ventilation, and it is more likely than CO_2 to raise health concerns. However, CO_2 monitoring may be useful in some circumstances e.g. in naturally ventilated spaces where there is no easy air flow rate measurement, and where there are concerns that ventilation may not be sufficient (e.g. people complain of stuffiness), particularly where occupants may operate their windows less often for example during cold periods, or on noisy sites, or on ground floors due to security concerns.
- Other pollutants may be identified as specifically relevant to the site e.g. near factories or intensive agricultural sites.

February Peak Bedroom CO_2 Levels (MVHR and Non-MVHR)



Source: Sharpe, McGill and Gupta, Characteristics and performance of MVHR systems - A meta study of MVHR systems used in the Innovate UK Building Performance Evaluation Programme, 2016

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What to do with the results?

Care should be taken not to draw excessive conclusions from the monitoring, particularly in the case of a single home or small sample of dwellings. There will be variations in temperature from one year to the next due to weather. In addition, and most importantly, there will always be large variations in IEQ, even between two identical dwellings, due to occupancy patterns (density, lifestyles patterns such as stay-at-home vs out-working-all-day, cleaning and cooking habits etc). On schemes with several dwellings, it can be very useful to look at trends across the whole scheme, including averages and extremes.

The IEQ measurements should be compared to the targets set at the design stage, if any; it is also useful to relate them to best practice, regulations, and the World Health Organization (WHO) recommendations for indoor air quality – CIBSE TM40 provides a summary of these for all IEQ parameters, allowing benchmarking. Significant discrepancies from WHO guidelines should be noted, and an investigation into possible causes and remediation measures should be carried out. Options may vary and some may be relatively simple e.g. “flushing” if high VOC levels, re-commissioning if poor ventilation (although this should have been carried out as part of the core BPE exercise); in other cases options may be more difficult to implement e.g. overheating mitigation if high summer temperatures etc.

This is an area where findings must be carefully communicated to inhabitants, as they should be aware of health implications and as the findings may be related to the building and its systems, as well as patterns of occupancy.

Pollutant levels that are higher than regulatory limits (e.g. from HHSRS or Building Regulations Part F performance guidelines) must be noted and raised with the client and project team, as they could be a health risk in the short or longer term. This is likely to require action beyond a performance-focused exercise, and may have contractual and/or legal implications.

Interpreting the results and assessing the need for further action must take account of the fact that people do not experience comfort in the same way, so the same conditions may lead to different experiences, and these experiences should not be dismissed. Furthermore, the same conditions could lead to different experiences and symptoms due to underlying conditions such as medication, health conditions, age etc.

Alongside benchmarking, results should be put into context, including weather, patterns of use, and correlation with findings from the other BPE techniques.

Looking at patterns

As for any monitoring (similarly to patterns of energy and water use), it is always useful to look at patterns of data, rather than just averages. This is particularly the case with air quality, as the data can be relatively inaccurate, making the absolute numbers less valuable than the patterns to identify the seriously of the issue and the likely causes.

The analysis of patterns should include, for example:

- Weekday / weekend
- Day / night, considering the likely activities in each room
- Summer / winter
- Variations throughout the day, and at night
- Variations with the weather e.g. cold / hot days, windy or still, low or high pollution...

These variations should be examined for each room, considering the activities likely to take place and the occupancy patterns. For example:

- Stable temperatures over one season are a sign of good comfort levels (instead of winter internal temperatures which would drop on cold days, or peak on hot summer days)
- Temperatures which do not drop when they should (e.g. when the home is unoccupied) are often a sign of inefficiencies: for example, the heating may be left on, or there are too many gains from surrounding communal areas, which could also lead to overheating.
- Inversely, temperatures which drop significantly in some rooms for long periods could indicate fabric inefficiencies and/or occupants only heating the room they occupy at that time, a possible sign of very eco-conscious behaviour but, most often, of concerns about heating bills and fuel poverty.
- it should be possible to identify cycles of washing, showering and cooking in humidity readings; this is a good sense check on the data. Humidity levels that do not return to normal would indicate ventilation not working properly
- these cycles of activities may also be reflected in the levels of VOCs (= from cleaning and consumer products) and PM (= possible indication of poor appliances and/or poor ventilation of cooking gases).
- On polluted sites, variations in PM levels may reflect variations in outside traffic, or occupants openings their windows.

- It would be expected that CO_2 levels would increase in bedrooms overnight, and in living rooms particularly at times of higher occupancy e.g. family meals. What is important is to check whether they return to normal once the room is less occupied, or whether levels are consistently over what is considered acceptable.
- Etc ...

Correlation with other BPE findings

Findings from IEQ monitoring should be examined alongside those from the other BPE techniques, so that IEQ performance is looked at holistically taking account of fabric performance, building systems, and occupant feedback and behaviours.

For example:

- Consistently high humidity readings vs site observations of mould growth vs ventilation performance
- Monitoring of indoor temperatures vs energy consumption: low energy and temperatures within comfort bands, without occupant complaints, would indicate well-performing homes; low energy but winter temperatures regularly below comfort bands could indicate long periods where the homes is unoccupied, or fuel poverty concerns from inhabitants under-heating their homes (e.g. keeping them at low temperatures, or only heating certain rooms)
- Temperature monitoring vs occupant feedback on winter and summer comfort
- Humidity or CO monitoring vs occupant feedback on perceptions of air quality

Next steps

Where design stage targets and/or good practice benchmarks are not met, some investigation should be carried out using the other BPE findings, leading to the identification of a number of likely causes, remediation options, and areas which warrant even more detailed investigation e.g. occupancy patterns analysis, window openings – see detailed ***occupancy feedback evaluation*** in section 5.11.

See important note above in case pollutants are found above regulatory limits. Concerns should also be raised if complaints from inhabitants are severe and persistent, and there are reasons to believe they could be at least partially linked to the building e.g. respiratory issues related to indoor pollutants or mould.

For detailed BPE, more suited to academic exercises or deep applied research, a more comprehensive assessment of conditions leading to thermal (dis)comfort would consider air movement and radiant effects from surface temperatures, as in practice they both contribute to perceived comfort, alongside air temperature and humidity. This would require measuring air velocity using either a fixed or portable anemometer and investigating wet-bulb radiant temperature.

5.3.6 Doing it “light touch”

The rest of this section describes a formal and detailed IEQ monitoring, which would involve experienced professionals and probably specialised and (at least in part) expensive equipment. However, as part of the initial (core) BPE exercise, the BPE team may find it useful to carry out their own checks of some IEQ conditions. This could involve:

- spot checks with their own portable sensors during the site visit, for example for temperature, humidity, or portable sensors for PM and VOCs - Refer to design section for guidance on the location of sensors to avoid misleading readings
- readings of the temperature and humidity sensors installed in the home
- short-term monitoring by leaving sensors between two visits (for example, between the summer and winter comfort surveys).

This will typically use cheaper and less accurate and reliable equipment, and will be carried out over short periods which may not be representative, so results really should be looked at with caution in order not to over-interpret. The readings should be seen as a sense check against site observations, user feedback, and other parts of the BPE exercise.

In any case, the BPE team should take a note of when the readings were made, so they can be related to local weather conditions e.g. wind direction and speed, outdoor temperature.

5.3.7 How to make it happen: who to do it, equipment, cost and time implications

Timing is not critical, but for temperature and humidity an extended monitoring period covering several seasons is often helpful. If an overheating concern has been raised then monitoring should include at least one summer period (May - September).

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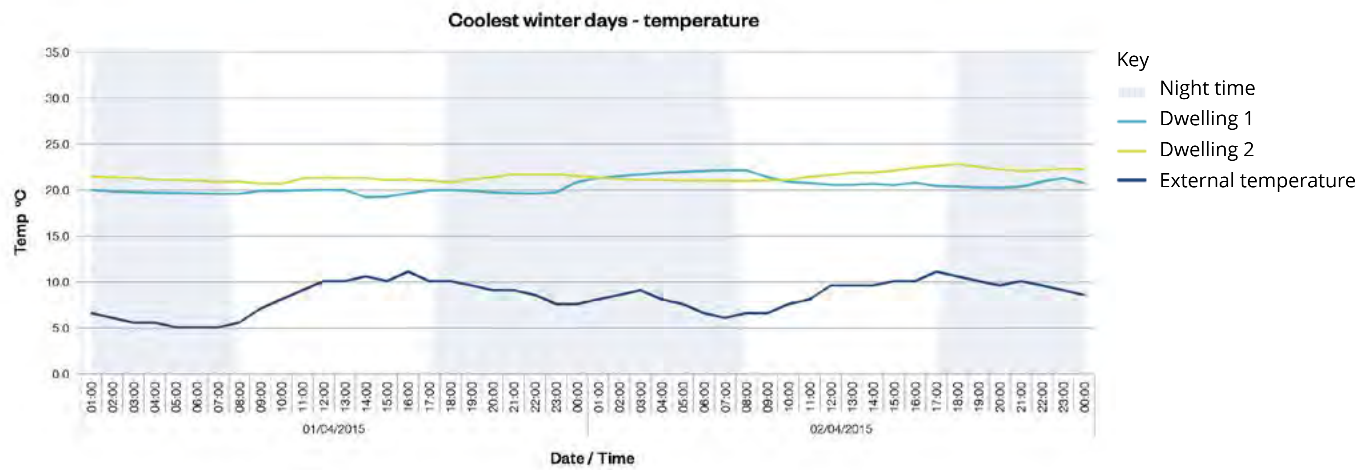
Temperature and humidity sensors are widely available, and many will be suitable for most BPE studies. For indoor air quality however, the sensors are of much more variable cost and quality. The BPE team may find it useful to utilise a mix of equipment: medium quality sensors deployed across the site, but used alongside a small number of higher quality ones, which are used for sense checks and calibration.

IEQ monitoring as part of a detailed BPE exercise should use accredited equipment, and possibly an accredited lab; this is recommended if the measurements or monitoring are done in a contractual or legal context, or for air quality if there are health concerns. This will help ensure reliability of data, not only through the equipment itself but how it is installed, calibrated, and used. Note that equipment used over longer periods (more than a year) will need regular re-calibration.

It is recommended that the exercise should be overseen by an experienced BPE professional, as it requires careful analysis to interpret the findings, identify suitable action as a result, liaise with inhabitants on the findings and possible causes, and identify whether issues are a serious health concern and need action beyond the BPE exercise itself.

In the case of simpler IEQ spot-checks carried out to complement a core BPE exercise, cheaper equipment may be used by the BPE team themselves, noting that readings may be less reliable.

Illustration of temperature monitoring: internal temperature in 2 dwellings, shown alongside external temperature. Even on cold winter days, internal temperatures were stable. This was examined together with heat consumption data and occupant feedback, showing a good overall performance for both comfort and energy efficiency.



Source: Bernstein, Loudoun Road post occupancy evaluation report, 2019.
Freely available at: www.levittbernstein.co.uk/research-writing/loudoun-road-post-occupancy-evaluation

5.3.8 Regulatory requirements

Apart from requirements related to health and safety, such as radon (in affected areas) and carbon monoxide sensors, regulatory requirements related to IEQ are generally that homes should be comfortable and with suitable fabric and ventilation provision to limit the risk of condensation and mould growth, but without set requirements for the conditions to achieve nor for monitoring to take place.

Routine monitoring of indoor conditions in homes is not generally required by regulations.

The main regulatory instrument at the in-use stage is the Housing Health and Safety Rating System (HHSRS) for occupied tenanted homes, if problems such as overheating, mould growth or condensation are reported to the Local Authority's environmental health department. This may change in the next few years due to the reforms of the Safety Regulatory Regime.

Approved Document F of Building Regulations includes performance objectives for some pollutants, although these are guidance rather than strict requirements. This may change with the upcoming revision to Part L and associated Approved Documents.

5.3.9 References and Further Information

CIBSE TM40, Health and Wellbeing in Building Services, 2020

CIBSE Air Quality Task Group, Technical Bulletin - Breathe Easy - Volatile Organic Compounds, Dzhordzhio Naldzhiev, UCL & Edwin Wealend, Cundall, October 2019: guidance on VOCs, harmful levels, and testing and monitoring equipment

Public Health England, UK Radon www.ukradon.org/ : maps, regulations, guidance, and testing kits to order.

5.4 HEAT TRANSFER COEFFICIENT: CO-HEATING

Important note: at the time of writing, co-heating tests are the main accepted method for measuring heat transfer coefficients (HTC), and they are the ones covered here, as a Detailed BPE exercise. However, the BEIS SMETER trials are evaluating options which would, if successful, provide measurements of the HTC in an easier, cheaper and less intrusive way. If this was the case, such tests could usefully be part of a core BPE exercise. Results from the SMETER trials are expected Q2 2021. In the meantime, such tests are covered as an innovative BPE techniques, in Section 6.

5.4.1 Overview of the technique

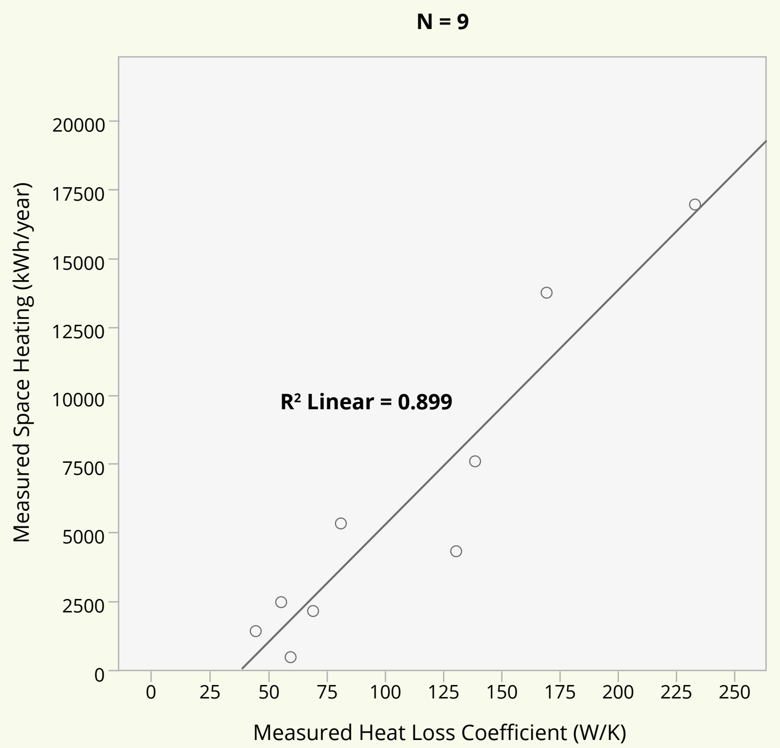
Co-heating tests are used to measure the total amount of heat lost through the thermal envelope of completed buildings. Simply put, they assess the amount of energy required to maintain a building at a given temperature. They require the involvement of specialists, to some extent due to the equipment required and, importantly, for the analysis.

Results of co-heating tests are expressed as a building's heat transfer coefficient (HTC) in W/K which represents the rate of heat loss per unit of temperature difference between inside and outside. This HTC can be compared with design estimates produced by calculations such as SAP and PHPP. For comparison with benchmarks and other buildings, it can be useful to normalise the HTC to floor area, and express it in W/m²/K.

An advantage of HTCs is that they reflect overall thermal performance of the building envelope, including the effects of elemental U-values, thermal bridging and airtightness; they provide a quantitative assessment, which can be directly compared with design targets and estimates (as opposed to, for example, thermography tests, which are mostly useful in a qualitative manner).

It is important to note that HTCs provided by co-heating tests are not strictly speaking 'full' HTCs as per the official definition (see definition in section 7.3): they take account of fabric losses through transmission and infiltration, but usually the ventilation inlets are blocked and systems closed during the tests, so the resulting HTC does not take account of ventilation and its effect on space heating (e.g. whether or not there is heat recovery). Saying that, nothing in theory prevents co-heating tests from being carried out with ventilation systems on to simulate actual in-use conditions, and this is currently the case in trials of alternative co-heating tests using metered energy use – see > ***section 6.2***.

HTCs have nonetheless been shown to be good indicators of space heating demand – see illustration below.



The heat transfer coefficient measured from co-heating tests is a good indicator of fabric performance: despite being on a small sample (9 dwellings), the Heat Loss Coefficients (or HTC) measured by co-heating tests show a strong correlation to measured space heating. The correlation appears stronger than between airtightness and space heating, which would make sense since the HTC takes account of airtightness as well as fabric heat loss through elements and thermal bridges.

Source: State of the National report, 2019 – see references

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In addition, HTCs cannot identify the sources of heat losses and therefore likely remediation measures; they also require the building to be empty, but heated, for a reasonably long period of time (typically 2-3 weeks), which is an important programme consideration and is in itself energy intensive.

Because of their limitations, co-heating tests are not appropriate on most projects and not recommended in routine BPE. However, they should be considered in detailed studies and on prototype properties, where they can help assess thermal performance before the roll-out of the prototype across larges schemes.

To address some of these limitations, alternative methods are being explored based on measured in-use energy consumption, allowing tests to be carried out when buildings are occupied or over much shorter periods. These methods are at various development, commercialisation and validation stages, but some may become common very soon, and BPE teams should remain informed of their potential. See > sections 6.2 and 6.3 ***SmartHTC*** and ***dynamic co-heating tests***.

Specific considerations for timber construction

The co-heating test may lead to drying of the timber, which could affect airtightness. It is therefore important to test airtightness pre- and post- co-heating test.

5.4.2 Guidance and application – design stage

Co-heating tests are not used at the design stage as this is a test applied at the as-built or in-use stage. Design considerations for fabric performance will improve the HTC.

An estimate of the HTC is carried out as part of SAP calculations and can be obtained from the worksheet. **Note however that it cannot be directly compared with results from the co-heating tests, since these are usually carried out to measure fabric performance, and are performed with ventilation openings and systems off or blocked.** By comparison, the SAP "heat transfer coefficient" follows the full definition of the HTC (see > ***appendix 7.3***) and also includes losses related to ventilation (SAP worksheet Box 39 in SAP 2012 version 9.92 (Rev Feb 2014) and in DRAFT SAP 10.0, July 2018). It is possible to make comparisons, as the SAP inputs include all relevant information, but this requires a little processing to separate the effects of fabric, infiltration and ventilation.

5.4.3 Guidance and application – in construction

n/a as this is a test applied at the as-built or in-us stage.

5.4.4 Guidance and application – completion and handover

While co-heating tests have been used since the 1980s, there is no industry-standard methodology for carrying out the test and analysing the data. A common method is that described by Johnston et al, 2013. Under these conditions, testing is estimated to have an accuracy of +/- 10% (*Jack et al, 2017*).

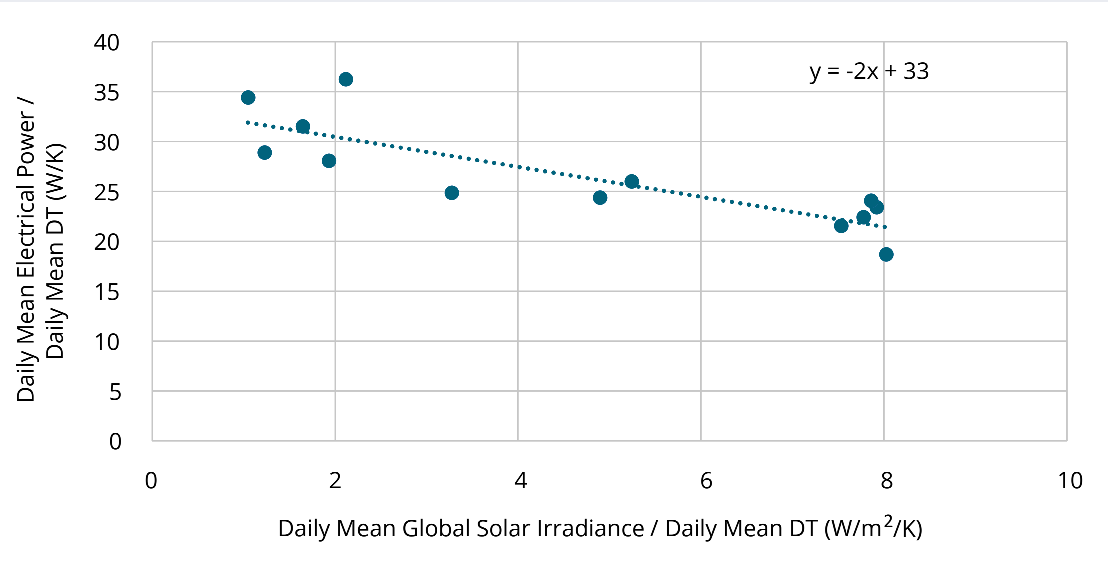
The test is usually carried out as follows:

- The dwelling must be unoccupied, all systems and appliances switched off
- Heating systems turned off, with electric heaters installed for the test, set to maintain a constant internal temperature - usually 25oC +/- 0.2°C. The test area should comprise all spaces that are intended to be conditioned in normal operation.
- The temperature difference between inside and outside should be at least 10°C.
- All ventilation systems shut off, and inlets / outlets sealed
- Adjoining dwellings need to be accounted for in the measurement and analysis. Ideally, they would be empty and heated to the same temperature as the test dwelling. If this is not possible, heat flux sensors on the adjacency walls need to be installed.

Following 1 or 2 days of observation to ensure the internal temperature is stable and homogeneous throughout the building, heating is maintained in order to gather at least one week of valid data, which usually requires a period of 3 weeks.

As part of the analysis of the results, heat losses from infiltration will be estimated. An air pressure test (see > ***core BPE***) should therefore be carried out before and after the co-heating test, and the results averaged for the analysis, as heating during the test period may cause drying of materials, potentially altering the infiltration rate. As detailed in the section on airtightness (see > ***core BPE***), this may particularly be the case in timber construction.

The data on energy input against temperature difference with the outside is then analysed in order to derive the HTC. Because of variations, especially in weather, specialist analysis has to be carried out to correct for factors such as wind and solar radiation – see illustration below.



Home Grown Homes – Chiltern Close: Example of results curve to obtain the HTC from measurements in a co-heating test. The results have to take account of the temperature difference between inside and outside (DT), and the daily mean solar irradiance, to correct for solar gains (source: courtesy of Build Test Solutions)

See also innovative methods >: in sections ***6.2*** and ***6.3***

What to do with the results?

One of the advantages of the co-heating test is that HTCs can be calculated from the fabric specifications, so results can be compared with calculations and targets.

Co-heating tests are not, however, diagnostic tests; if heat loss is higher than expected, other BPE techniques need to be applied to determine what may be the reasons and remediation measures:

- Transmission heat losses: U-value measurements are often carried out at the same time as co-heating tests. This is also a specialised technique, and people carrying out co-heating tests will usually be able offer U-value measurement services too. This does not however look at heat losses from thermal bridges. For this purpose, it is useful to carry out a thermographic survey at the same time as the co-heating test, as these surveys also require a temperature difference between inside and outside – see > ***detailed BPE***; this will give an indication of higher heat loss areas, including thermal bridging, but no quantification. For a really detailed study, thermal bridge analysis may be carried out to quantify the effect of thermal bridges – see > ***detailed BPE***.
- Infiltration heat losses: see core BPE > ***airtightness testing***.

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5.4.5 Guidance and application – in use

As for "at completion", but needs building to be empty of inhabitants so not "in use".

To address some of the limitations of the co-heating test, especially its duration and the fact that buildings need to be un-occupied, alternative methods are being developed - see > innovative methods >: ***HTC from measured energy consumption***.

5.4.6 How to make it happen: who to do it, equipment, cost and time implications

Co-heating tests have important programming implications:

- they typically need to cover a period of 1-3 weeks, during which the building should be unoccupied and as little disrupted as possible
- a temperature difference of at least 10oC between inside and outside (cooler outside) is required, which means they are typically carried out in winter.
- The building envelope needs to be complete i.e. finished with all doors and windows fitted, and air tight (i.e. plastering finished). An air pressure test should be carried out before and after co-heating tests.
- It is not necessary for heating and ventilation systems to be complete and commissioned, as the tests are carried out with ventilation systems off and sealed, and heating is provided by electric heaters.

This means that, if co-heating is to be carried out, a suitable period for it should be incorporated early on in the programme, as the tests would otherwise not be possible or they could seriously affect completion and handover.

There is no standard method and accreditation for co-heating tests and the individuals carrying them out, therefore the tests should be procured from accredited labs (e.g. BSRIA) or individuals and organisations with a proven track record. The quote should make it clear whether or not additional services are proposed to be carried out at the same time (e.g. U-value measurements, with details on which building elements are proposed to be measured).

Air pressure tests need to be carried out before and after co-heating tests. It should be possible to source both airtightness and co-heating tests from the same company, but it is not necessary. The quote from the co-heating testing companies should clearly state whether pre- and post-airtightness tests are included, or whether they need to be sourced at additional costs or from another company.

The following equipment is needed:

- Electric fan heaters, with meters allowing logging (typically, every 5 minutes)
- Circulation fans to ensure mixing and homogenous temperature in all rooms
- Temperature and relative humidity sensors, linked to logging
- Weather station (wind measurement, solar radiation, outside temperature and relative humidity).

Home Grown Homes – Pentland Close:
Equipment in place for a co-heating test (note the fan, towards the rear of the picture). Heat flux plates are shown on the walls and ceiling to do U-value measurements at the same time, as is typical practice during a co-heating test.
(Picture courtesy of Diana Waldron)

Innovative tests based on in-use energy consumption can be carried out any time, with no disruption to inhabitants, and therefore require minimal if any programming, but these are still in development – see sections ***6.2*** and ***6.3*** .

5.4.7 Regulatory requirements

There is currently no requirement in Building Regulations or other regulations for testing of the as-built or in-use HTC. It is possible that this will be introduced in the future, but probably only if methods that are less time-intensive and disruptive than the current co-heating test are validated.

5.4.8 References and further information

R. Jack, Loveday , Allison D., and Lomas K., First evidence for the reliability of building co-heating tests, Building Research & Information Volume 46, 2018 - Issue 4, March 2017 www.tandfonline.com/doi/full/10.1080/09613218.2017.1299523

BSRIA, Sarah Birchall, "What is a co-heating test?", 2011
www.bere.co.uk/assets/Uploads/agm-2011-co-heating-tests-sarah-birchall-3.pdf

This video is subtitled, but gives an introduction to the technique: www.youtube.com/watch?v=IGEwl6wxVSQ

GUIDANCE ON DETAILED BPE TECHNIQUES

5.5 THERMAL BRIDGE ANALYSIS

5.5.1 Overview of the technique

Following an initial thermal bridging review - see core BPE section 4.6, it may be appropriate to carry out a more detailed thermal bridging analysis where details are non-standard or higher risk for thermal bridging, or with very ambitious energy targets (e.g. Passivhaus, which requires "thermal bridge free" envelope). When this is the case it is recommended that thermal bridging calculations are commissioned. Thermal bridging analysis is not straight-forward and usually requires an expert.

This analysis could also be triggered during construction or at practical completion or in use, e.g. if visible mould or condensation, or by thermography highlighting risk area.

Related BPE techniques:

- For an initial review, see Core BPE > ***thermal bridging*** review section 4.6
- for a qualitative assessment of thermal bridging, see > ***thermography*** section 5.2.

5.5.2 Guidance and application – design stage

Thermal bridging calculations should be done at the design stage whilst there is still the opportunity to refine construction details to reduce heat loss, and improve buildability.

The process of thermal bridging analysis is:

- Following the thermal bridging review (see Core BPE > ***thermal bridging review***), identify the details for which thermal bridging calculations are already available e.g. from ACDs (Approved Construction Details).
- Calculate the Ψ value for all non-standard details (i.e. all the details for which calculations are NOT already available)
- Calculate the Y value for each unit and compare against any design target.
- Get the calculations double-checked (they are detailed and mistakes are very easy to make)

It is helpful to consider how complex details will actually be constructed including any sequencing issues so that these can be flagged up to site teams.

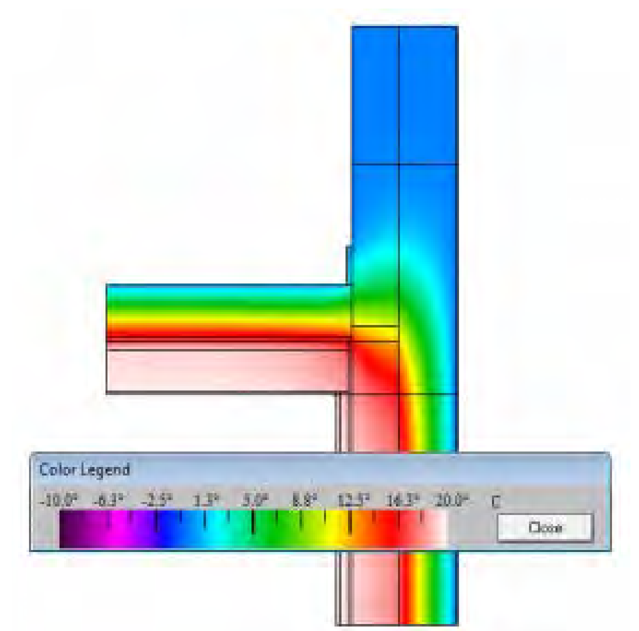

Illustration of thermal bridging modelling results
Source: Peter Warm www.peterwarm.co.uk/thermal-bridge-analysis

What to do with the results ?

Keep records of the thermal bridge analysis carried out.

If targets are very onerous targets, then it is really important that the individual carrying out thermal bridging calculations are experienced, and ideally that the calculations are double-checked as they are fiddly and mistakes are commonplace.

5.5.3 Guidance and application – in construction

Following a design stage thermal bridge analysis, care should be taken during construction to ensure that details are built as designed, and questions raised to the design team where there is any doubt.

See also > ***site inspection*** core BPE to ensure construction is as per agreed details. This may require additional appointment, depending on the level of detail and the amount of construction details to be checked.

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5.5.4 Guidance and application – completion and handover

As per construction stage, checking the as-built details against calculations and updating the analysis if required.

5.5.5 Guidance and application – in use

A thermal bridge analysis can be done for diagnostic purposes at the in-use stage if concerns are raised (e.g. mould growth), but remediation options may be limited without significant intervention on the building envelope, so the team should discuss whether it is worth engaging in what can be a time-consuming and costly exercise.

5.5.6 How to make it happen: who to do it, equipment, cost and time implications

In the UK, thermal bridging analysis must be carried out using software calibrated to ISO 10211:2007 – the most widely used tools are THERM, Psi-Therm and TRISCO.

The physics of these calculations is complex, so a knowledgeable expert should be engaged to be sure of reliable results. No qualifications are required, but reports must include significant design information so that the calculations can be repeated. The calculations are complex, so human error is common and it is recommended that all calculations are double-checked by somebody with experience.

The time and associated costs of analysis and calculation of an average Y-value depend on the size and complexity of the project. Cost-effectiveness is achieved through calculating the highest-impact junctions first (such as the window reveals, roof and ground floor perimeter details) and undertaking subsequent calculations as needed, until the targeted value is reached.

Whilst the cost for thermal bridging calculations on a single dwelling could be significant, there are significant economies of scale for larger schemes.

5.5.7 Regulatory requirements

Building Regulations Part C and Approved Document C require continuity of insulation and minimising the risk of condensation and fabric degradation. This may trigger the need for thermal bridge analysis following BS 5250.

5.5.8 References and Further Information

Building Regulations Part C and Approved Document C
www.gov.uk/government/publications/site-preparation-and-resistance-to-contaminates-and-moisture-approved-document-c

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5.6 MOISTURE DYNAMIC ANALYSIS

5.6.1 Overview of the technique:

This technique uses a dynamic hygrothermal simulation tool, to predict the way heat and moisture move through a construction. It can be used to assess the risk of moisture accumulation within any part of a wall, floor or roof build-up, and to inform design decisions that reduce these risks.

Specific considerations for timber construction
High and sustained moisture levels is a greater risk in timber construction as it can cause material degradation (rot) and ultimately can lead to structural failure.

5.6.2 Guidance and application

This technique should be used at the design stage where there is a risk that moisture within the construction will not be able to dry to the outside, or could accumulate internally. Complex details should be assessed by an expert, and if the analysis shows up problems the details should be redesigned so as to resolve them as rectifying details post construction is much more challenging.

It can also be used to help diagnose post-construction issues spotted on site including mould formation, inhabitant feedback or following a thermographic study

5.6.3 How to make it happen: who to do it, equipment, cost and time implications

The most commonly used tool is WUFI®, other tools include the 'Glaser Method' which is commonly referred to as an 'interstitial condensation check'.

Hygrothermal analysis is a highly specialised technique, so it requires the appointment of an expert. This may require asking for recommendations, for example from people working on Passivhaus projects, timber construction, or traditional buildings (buildings of traditional construction are usually built to allow the flow of moisture and retaining this is particularly important to conserve the fabric, so hygrothermal analysis is less uncommon in this sector). The UK Centre for Moisture in Buildings may be able to provide recommendations.

The expert performing the analysis should be able to understand the problem and how the design might be adapted to alleviate the risk.

Costs will vary depending on the scale of the analysis required i.e. the number of details requiring analysis and the complexity of the details. Because of the time and expertise required, it is not cheap, hence why applying best practice principles and a thermal bridging review first is useful to determine whether this will be required, and if so to define the scope of the analysis.

5.6.4 Regulatory requirements

A requirement for this type of analysis could be triggered by Building Regulations Part C or requirements under BS EN ISO 13788:2012 'Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation.'

5.6.5 References and further information

Building Regulations Approved Document Part C: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/431943/BR_PDF_AD_C_2013.pdf

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5.7 ENERGY MONITORING AND ANALYSIS - DETAILED

5.7.1 Overview of the technique

This technique follows on from the ***core BPE – energy audit*** and involves a much greater granularity of monitored data – particularly more frequent time steps and sub-metered end uses e.g. using smart meter data or on site energy monitoring to understand energy consumption across seasons and unit types. It is usually used where research has been commissioned into domestic energy consumption due to use of a new building technique or construction type, or in response to particular concerns.

5.7.2 Guidance and application – design stage

n/a

5.7.3 Guidance and application – in construction

n/a

5.7.4 Guidance and application – completion and handover

n/a

5.7.5 Guidance and application – in use

Aim to collect in-use energy data for at least for one year.

The technique will usually involve the installation of dedicated monitoring equipment for the purpose of the BPE study, although smart meters have considerably expanded what is possible without additional equipment. There are two complimentary approaches to this type of monitoring.

Use of existing smart meters - these are installed by electricity suppliers, and take frequent meter readings that can be utilised for monitoring purposes. Different suppliers enable access to this data in variable ways, but in principle home owners could have access to 5 minute electricity readings and half hourly gas readings. As all new build homes are fitted with smart meters this is potentially a low-cost information resource. Smart meters are typically only available for main energy supplies, although it may be possible to use clip-on meters (see below) applied to specific cables to break down consumption.

Access to this granular data on energy consumption enables various conclusions to be drawn from night time consumption rates, week day daytime consumption rates, peak consumption levels and durations etc.

Sub-metering - these can be temporary meters that clip on to the power cable connected to the electricity meter to monitor the magnetic field around the power cable and measure the amount of energy being used; or permanent sub-meters. In either case these should report to a local device for logging and display.

Sub-metering enables the total energy used to be broken down into the energy used for space heating, hot water generation, cooking plug loads, car charging and any renewable generation on site e.g. from PV. This split can then be compared to any predictions from energy modelling or suitable benchmarks to help diagnose any areas of energy use that are higher than anticipated.

Monitoring energy consumption for heat pumps (inputs, outputs, seasonal averages and on peak winter days) can enable actual coefficients of performance (COP) to be calculated, and compared against manufacturer data. Poor performance can indicate that controls for heat pumps have not been optimised.

Commissioning this equipment should include ensuring that the data recorded by all sub-meters reconciles with the main meter readings i.e. that they all add up.

Most monitoring projects will need to use both approaches.

It is recommended that a weather station is installed on site for the duration of the modelling so that ambient weather conditions can be compared with the result profiles - see > ***weather station*** section 5.1.

What to do with the results?

For avenues of analysis, see the section on the Energy Use Audit: the principles will be similar, but applied at a higher level of accuracy in this case, as energy use data will be available broken down into end uses and/or areas, and possibly on smaller time steps (e.g. from half-hourly or, at least, monthly, rather than just annually in the case of the simplest energy use audits).

As for the simple energy audit, results must be compared with those from other BPE techniques, including the fabric performance tests, water use audit (or a more detailed analysis), feedback from users, and site observations.

It is valuable to compare in-use energy consumption data against design stage energy modelling predictions - see > detailed BPE ***Energy Modelling*** in section 5.8, and to targets set at the design stage. Significant variations from targets should be investigated and, if possible, explained by the exercise.

The analysis must be done in liaison with inhabitants, as patterns of occupancy will have a strong influence on energy consumption, particularly on individual homes or smaller schemes – see privacy and ethics section.

The analysis should aim to identify overall performance and that of individual elements (e.g. space heating, hot water, ventilation), causes for under-performance and possible remediation measures, and wherever possible the influence of occupancy patterns.

Next steps

This will depend on the findings.

For example, in the case of high heating demand: the analysis may conclude that under-performance relates to a high space heating demand caused by poor fabric performance confirmed by BPE tests on the fabric (e.g. airtightness test, U-values).

On the other hand, it could conclude that fabric performance is good, occupancy patterns as expected, but energy use related to space heating higher than expected and a more detailed analysis of the performance of heating plant is required (beyond a commissioning review and re-commissioning).

5.7.6 How to make it happen: who to do it, equipment, cost and time implications

There can be some cost associated with the purchase and installation of sub-metering and logging equipment, but the main cost will be in the time of experts to collate and analyse the data. Time and care are required for processing the data collected and interpreting it. In addition, the preparation phase i.e. making sure data will be available, reliable and meaningful, must not be under-estimated when procuring the BPE work.

Large amounts of data can be generated by such an exercise so it is recommended that expert advice is sought to maximise the useful findings from this exercise. It is a good idea to have clear objectives for what the study is aiming to determine.

It is helpful to link this work to any IEQ monitoring data as internal temperature and humidity patterns will be relevant in assessing the energy monitoring results.

5.7.7 Regulatory requirements

n/a

5.7.8 References and further information

The Usable Buildings Trust includes a database of past BPE reports, including those carried out as part of the Technology Strategy Board programme. These include several housing projects with detailed analysis of energy monitoring data over at least one year. This is a very valuable resource for detailed studies, and freely available: www.usablebuildings.co.uk/

GUIDANCE ON DETAILED BPE TECHNIQUES

5.8 ENERGY MODELLING

5.8.1 Overview of the technique

The energy review as part of the core BPE exercise may determine that detailed energy modelling is recommended, for example if onerous energy performance targets have been set, such as Passivhaus.

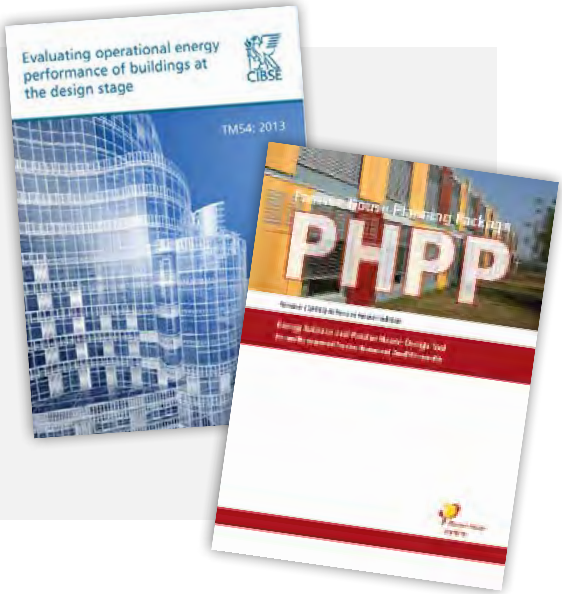
Detailed energy modelling can involve PHPP calculations (for Passivhaus) or Dynamic Thermal Modelling. Expert advice should be sought for either.

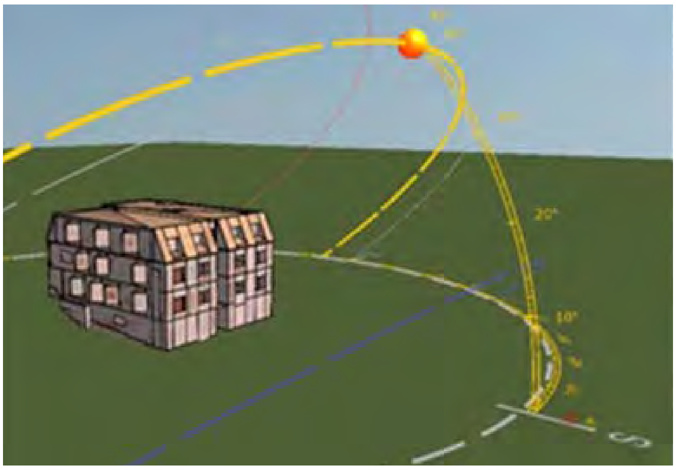
N.B. SAP calculations are not usually appropriate for this type of analysis as it is a compliance tool and not a good predictor of actual in-use energy performance.

Predicting the in-use energy performance of a new building is difficult because, in most cases, the inhabitants that will live in the home, and their lifestyle and preferences are not known.

There are two approaches to this difficulty:

- Model using standardised occupancy patterns and concentrate on ensuring the building design is as energy efficient as possible regardless of how it is occupied. PHPP takes this approach and is shown to provide robust predictions on this basis, particularly for space heating.
- Make best guesses as to occupancy patterns and then do sensitivity analysis to see how much changes in occupancy might affect the outcome (add error margins). Dynamic thermal modelling tends to utilise this approach. CIBSE TM54: *Evaluating Operational Energy Performance Of Buildings At The Design Stage* (see references) is helpful for describing how this process might work.





Home Grown Homes - Image of a thermal model showing solar angles being calculated *(courtesy: Diana Waldron)*

Modelling can be carried out at any stage of a building life cycle, but usually adds the most value when it is started early in the design process and carried forward all the way to the post occupancy stage. What defines a modelling exercise at any stage is what results are intended for.

At the design stage, modelling outputs are commonly used to inform design decisions, determine performance targets, and/or predict progress against energy and comfort performance targets.

At the in-use stage, they can be used to compare predicted with actual performance and identify possible improvements and reasons for under-performance.

GUIDANCE ON DETAILED BPE TECHNIQUES

5.8.2 Guidance and application – design stage

Detailed modelling can be used to inform the design proposals and performance targets. The two main techniques available are:

PHPP (Passive House Planning Package) is a steady-state spreadsheet tool that has been developed by the Passivhaus institute. It incorporates the energy specifications for quality-approved Passivhaus homes, and makes conservative assumptions throughout the calculation. It has proven to be a good predictor for heating energy consumption. The PHPP tool is a fundamental part of achieving Passivhaus accreditation and will be constantly referred to and updated by the Passivhaus consultants as the design evolves as part of ensuring that the targeted performance standards are being met.

PHPP is also sometimes used when the target is not Passivhaus, as it can still be very helpful as a design and prediction tool (especially for space heating).

Dynamic Thermal Modelling is a term that encompasses a number of different software tools which are differentiated by their ability to calculate hourly (or shorter) time step results. The tools use 3D geometry for the project, with thermal properties allocated for all construction elements, they import hourly weather data local to the site, apply daily profiles to internal gains and set points, include HVAC servicing strategies; and use these to predict hourly thermal conditions for each space and the resulting energy consumption. These tools are valuable for predicting overheating risk for schemes where this is a concern - see Detailed BPE > ***overheating analysis***.

Dynamic thermal modelling tools are used less frequently for energy prediction in homes (compared to non-domestic building types) as such models are sensitive to how they are occupied, and the occupancy patterns of homes vary significantly and are usually not known at the design stage. Models of this type are relatively complex, and the costs are rarely justified by clients on domestic projects unless there is a specific concern or research requirement.

The technique can be very helpful in refurbishment contexts as it allows the predicted outcome of different options to be compared against the existing base case.

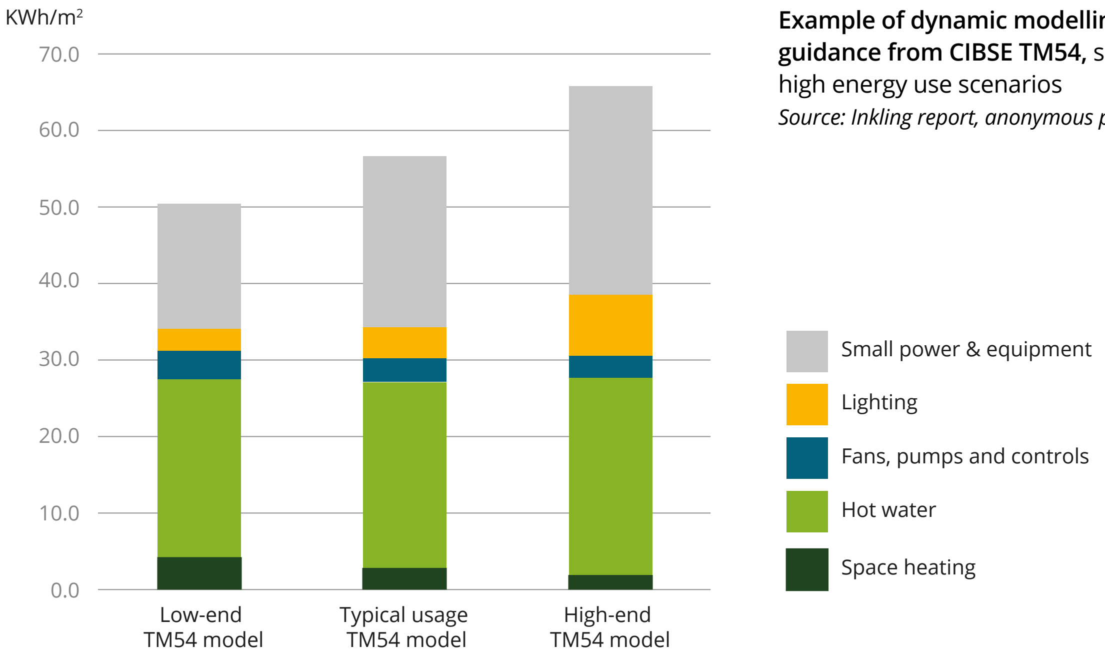
Widely used dynamic thermal modelling tools include DesignBuilder, Energy+, IES, TAS.

Neither PHPP nor dynamic modelling techniques provide definitive energy consumption predictions for each unit as individual occupancy patterns and preferences vary significantly, but aggregated predictions over a larger group of homes are usually more accurate as variations in lifestyle start to average out.

> “All models are wrong, but some are useful.”
>
> George Box

Illustration of the inputs required in SAP, PHPP and dynamic modelling - this gives an indication of the level of complexity and what is / isn’t considered

Inputs	SAP	PHPP	Dynamic thermal modelling
Geometry data	Y	Y	Y detailed for all rooms
External envelope construction and thermal properties	Y	Y	Y
Bespoke internal gains values and profiles	N	N	Y
Heating system type and efficiencies	Y limited selection of system types	Y	Y
Bespoke heating set point tmperatures and hours of use	N	N	Y
Air tightness, ventilation method plus supply volumes and any heat recovery	Y fixed supply volumes, limited system types	Y	Y
Location data and weather file	N	Local weather data including altitude	Latitude & longitude for calculating solar angles, & local weather files including options for future climate change scenarios



Example of dynamic modelling results, using guidance from CIBSE TM54, showing low/med/high energy use scenarios
Source: Inkling report, anonymous project

5.8.3 Guidance and application – in construction

Energy model inputs should be monitored and updated in response to any changes on site – see > ***Design review***.

5.8.4 Guidance and application – completion and handover

Updates to any model should be carried out to reflect final as-built values.

PHPP should be signed off by Passivhaus certifier, following a detailed as-built site visit and airtightness test.

5.8.5 Guidance and application – in use

Energy modelling results can be useful for comparing against energy monitoring data gathered once the homes are occupied. Monitoring studies can be more valuable when targets have been set based on energy models, as there is then a reasonable estimate of the potential performance of the home (rather than just a target). Any discrepancies between the model energy use predictions and the measured data can help diagnose the issues behind them – see guidance on interpreting results in Core BPE > ***energy audit***.

In some scenarios dynamic models can be updated to reflect actual occupancy patterns, and actual local weather data recorded during a monitoring period to get the modelled results closer to the monitored data.

5.8.6 How to make it happen: who to do it, equipment, cost and time implications

Energy modelling is often an iterative process with 'light touch' models initiated early in the design process to check basic principles and inform core design decisions (orientation, glazing areas, wall thicknesses etc). Models usually become more detailed at the planning stage.

When onerous targets are set, such as Passivhaus, tolerances are tight and therefore it is important that any changes to the specification are implemented within the model and compensated for elsewhere to maintain the overall performance. For example, PHPP models tend to be updated frequently to keep pace with the design, and this needs to be taken into account in the programme.

The Passivhaus Trust have a map listing all the certified designers/consultants in the UK: ***here***.

It is recommended that dynamic modelling assessments are carried out by experienced modellers using software compliant with CIBSE AM11 (see references).

Timescales for such modelling exercise can vary enormously depending on the number of units to be included in the study and the number of iterations that will be explored. It is wise to draw up a clear scope of the modelling exercise required and then seek several quotes.

5.8.7 Regulatory requirements

No requirement for energy performance modelling. Note that SAP calculations for the production of an Energy Performance Certificate (EPC) will still be required at completion, even if PHPP or dynamic energy modelling has also been carried out.

5.8.8 References and further information

www.passivhaustrust.org.uk/design_support.php

https://passipedia.org/planning/calculating_energy_efficiency/phpp_-_the_passive_house_planning_package

CIBSE AM11 - www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008JeYXAA0

CIBSE TM54 - www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I7f7AAC

GUIDANCE ON DETAILED BPE TECHNIQUES

5.9 WATER MONITORING AND ANALYSIS

5.9.1 Overview of the technique

This technique follows on from the core BPE – water use audit and involves a much greater granularity of monitored data – particularly more frequent time steps and sub-metered end uses e.g. using smart meter data or on site water monitoring to understand water consumption across seasons and end uses. It may be useful in conjunction with a detailed analysis of energy consumption, since a large proportion of water use relates to hot water and therefore has energy implications.

This must be done in liaison with inhabitants, as patterns of occupancy have a strong influence on water consumption but information on water consumption habits (e.g. how often they wash) can often be considered private and sensitive by occupants – see privacy and ethics section.

5.9.2 Guidance and application – design stage

n/a

5.9.3 Guidance and application – in construction

n/a

5.9.4 Guidance and application – completion and handover

n/a

5.9.5 Guidance and application – in use

The BPE exercise should aim to collect in-use water data for at least one year.

The technique will usually involve the installation of dedicated monitoring equipment for the purpose of the BPE study, as water sub-meters are very rarely installed on homes as routine, with the possible exception of sub-metering of central plant in large developments. The metering strategy should aim to capture:

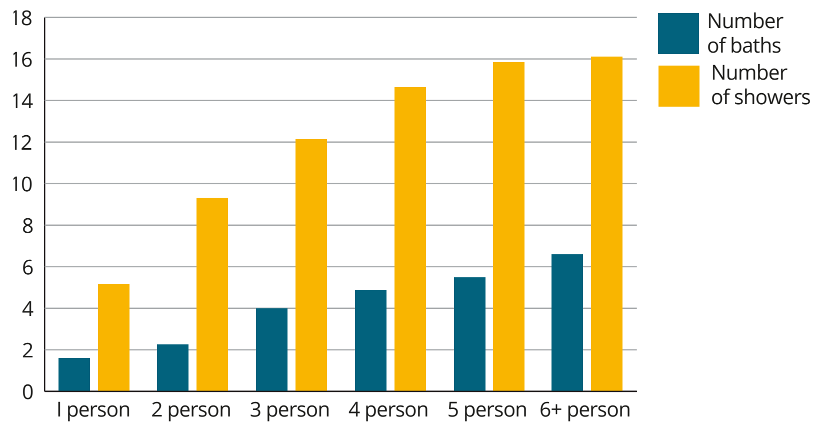
- Patterns of use: day/ night, weekend/weekday, seasonal
- Key sub-uses, with the kitchen and bathroom typically being the largest users. Ideally, this should differentiate cold-water from hot water uses, although this may be difficult depending on the pipework configuration. External water uses may be sub-metered separately (they are typically a small proportion of total use, but may also be those which leak without being noticed).

The findings can be correlated with a typical breakdown of water consumption (see breakdown of water use in ***chapter 4.12***) – this should consider total water use and, where possible, hot water separately, as this also has energy use implications.

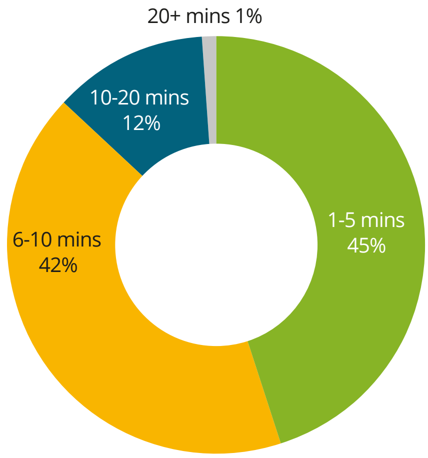
Bathrooms and kitchens are the largest energy users, and among these, the influence and showers and baths (number of them, and length of showers) should not be under-estimated.

Illustration of typical habits relating to showers and baths, with a strong influence on water consumption - Occupants habits will be highly influential on water consumption. A detailed analysis of water consumption must therefore be done carefully, alongside residents and having ensured that privacy and ethics implications are acceptable .

Number of showers and baths taken per household per week



Average time spent in the shower



(reference: Energy Saving Trust, At Home with Water, 2013)

Alongside metering, a review of appliances and fittings should be done to establish a list of them, and their ratings (e.g. litres/min for taps and showers, litres/cycle for dishwasher).

This should provide enough information to fill a water calculator and provide an estimate of expected consumption, on the assumption of no leak. The most commonly used calculator is the national one used for building regulations purposes.

Ideally, the calculator should be filled with the help of occupants, otherwise the BPE team should do it based on their best estimate using site observations and correlations with findings from other BPE techniques. On large sites, an average may need to be done, or for example a split into a few categories (e.g. family with stay-at-home parent, working couple, single adult; water-conscious vs profligate user…).

Comparing monitored data with the estimate from the calculator, alongside findings from other BPE techniques (including site observations, occupant surveys and interviews, and energy consumption analysis) should provide a good indication of likely causes for high water consumption and opportunities for savings.

Next BPE steps

For really detailed studies which are also concerned with the influence of hot water on energy use, and particularly on large sites where the influence of individual occupants would be lessened by the size of the sample, the BPE team may find it useful to correlate energy and water use with weather patterns, as the temperature of incoming water varies between summer and winter – see for example EST, 2008 in references. This would be best carried out an analysis of plant performance, this that plant efficiency will matter at least as much.

5.9.6 How to make it happen: who to do it, equipment, cost and time implications

There can be some cost associated with the purchase and installation of water sub-metering and logging equipment, although the BPE team may already have such equipment for temporary uses. In that case, the main costs will be in the time of experts to collate and analyse the data.

Time and care are required for processing the data collected and interpreting it. In addition, the preparation phase i.e. making sure data will be available, reliable and meaningful, must not be under-estimated when procuring the BPE work.

Large amounts of data can be generated by such an exercise so it is recommended that expert advice is sought to maximise the useful findings from this exercise. It is a good idea to have clear objectives for what the study is aiming to determine.

5.9.7 Regulatory requirements

n/a

5.9.8 References and further information

Energy Saving Trust report for DEFRA, Measurement of Domestic Hot Water Consumption in Dwellings, 2008
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf.

Energy Saving Trust, At home with water, 2013
www.energysavingtrust.org.uk/sites/default/files/reports/AtHomewithWater%287%29.pdf.

GUIDANCE ON DETAILED BPE TECHNIQUES

5.10 OVERHEATING ANALYSIS – DYNAMIC MODELLING

5.10.1 Overview of the technique

This technique uses dynamic thermal modelling tools to predict the likelihood of overheating occurring in the finished homes.

Dynamic overheating modelling is recommended if the core BPE – ***GHA overheating tool*** still indicates a significant risk of overheating once basic mitigation measures have been applied.

A full overheating risk assessment is sometimes a planning requirement.

It can also be triggered by concerns raised through Core BPE at the in-use stage e.g. temperature monitoring or user feedback, when the model could help establish the causes and possible improvement options.

CIBSE TM59 - Design Methodology for the assessment of overheating risk in homes.
This guidance was produced in 2017 and provides a detailed modelling protocol to assess overheating risk using dynamic thermal modelling tools, together with a clear pass/fail threshold. The modeller can use iterations of the model to explore mitigation options and test design revisions to reduce the overheating risk to acceptable limits.

TM59 also covers communal stairwells and corridors. These are especially important to consider where pipework distributing community heating passes through these spaces, there are large glazing areas, or no ventilation provision.

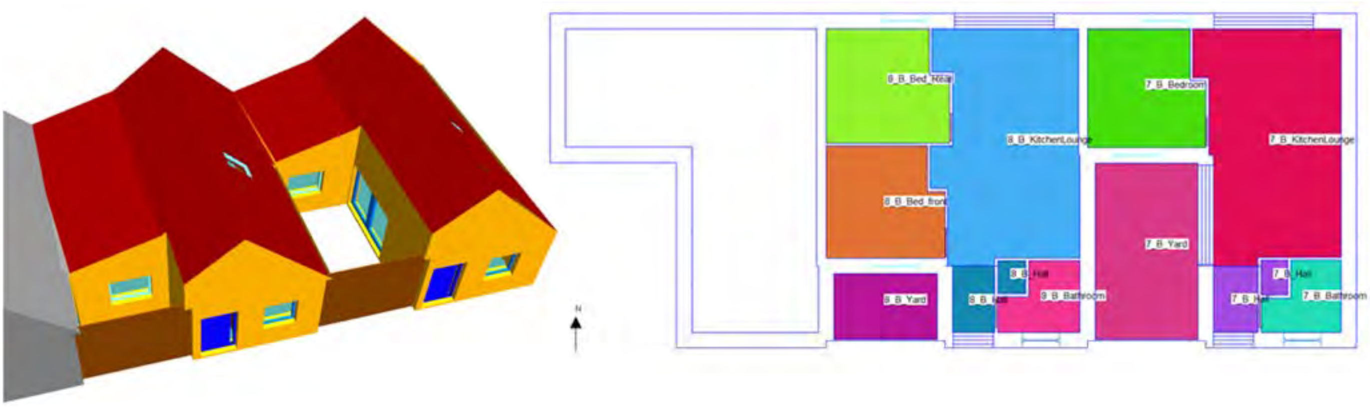
5.10.2 Guidance and application – design stage

It is important to assess overheating risk as early as possible in the design process and definitely pre-planning while changes to the facade can still be made to help mitigate any risk identified. Some planning authorities ask for TM59 overheating risk assessments as part of planning applications.

A TM59 report should include all the assumptions the modelling is based on, together with the results for all the iterations tested. The preferred solution should be clearly explained and the results for this case should demonstrate that all occupied spaces pass the criteria. Note that where there are communal stairwells or corridors, results should also be provided for these. If internal blinds form part of the mitigation proposals then these should be included and installed as part of the base build, and results without blinds should also be included in the report to reinforce their necessity.

GUIDANCE ON DETAILED BPE TECHNIQUES

Home Grown Homes – Clyro bungalows: Dynamic thermal model geometry and zone layout



Home Grown Homes – Clyro bungalows: Table of TM59 dynamic modelling results

Zone Name	Max. Exceedable Hours	Criterion 1: #Hours Exceeding Comfort range	Annual Night Occupied Hours for Bedroom	Max. Exceedable Night Hours	Criterion 2: No. of Night Hours Exceeding 26°C for Bedrooms	Result
1F_F_Bedroom	110	14	3285	32	0	Pass
1F_F_Kitchen Lounge	59	36	N/A	N/A	N/A	Pass
1G_F_Bedroom	110	0	3285	32	21	Pass
1G_F_Kitchen	59	0	N/A	N/A	N/A	Pass
1G_F_Lounge	59	0	N/A	N/A	N/A	Pass
2F_F_Bedroom	110	17	3285	32	0	Pass
2F_F_Kitchen Lounge	59	28	N/A	N/A	N/A	Pass
2G_F_Bedroom	110	0	3285	32	21	Pass
2G_F_Kitchen	59	0	N/A	N/A	N/A	Pass

5.10.3 Guidance and application – in construction

Once a model has been carried out, if changes to the design or specification occur during construction that are likely to have a bearing on the overheating risk then it may be helpful to review the impact of these changes within a model - typically this would include changes to the design or specification, but other factors may change too e.g. neighbouring existing building which would be demolished and not provide the shading initially assumed.

5.10.4 Guidance and application – completion and handover

Updates to any model should be carried out to reflect final as-built values.

See also > Core BPE - ***Handover review***, to make sure that any overheating mitigation measures are covered in the Building User Guide e.g. operation of shading devices, use of thermal mass wit night-time ventilation.

5.10.5 Guidance and application – in use

TM59 models at the in-use stage may be triggered by post-occupancy temperature monitoring data, and occupant feedback evaluation to test whether overheating is exacerbated by the design. Models can also be very useful to help assess and identify possible remediation measures.

TM59 models are sometimes used retrospectively to help resolve legal responsibility when homes overheat in practice.

5.10.6 How to make it happen: who to do it, equipment, cost and time implications

A TM59 overheating risk assessment would typically take 1-3 days for an individual dwelling and 3-5 days for 5-10 units. Further economies of scale apply to larger schemes.

TM59 assessments costs will depend on the number of units that need to be included. On a larger scheme it is acceptable to assess a sample of units selected from those likely to have the highest risk (the GHA tool and thermal modelling consultant can help with evaluating which these might be), but they are likely to be those with larger areas of glazing, on the top floor, have less shading, limited opening windows, acoustic constraints or single aspect. The sample size would usually be at least 10% of the total units, often more in smaller developments, and ideally include one of each unit type.

Larger house-builders may choose to model their standard unit types in different locations and orientations to build confidence and awareness for how units perform and which may require mitigation measures in certain positions.

The CIBSE TM59 methodology document (see references) is free to download with registration with the CIBSE website. There are some free dynamic thermal modelling tools, but it is a steep learning curve to become competent with these tools, and it is recommended that assessments are carried out by experienced modellers using software compliant with CIBSE AM11.

5.10.7 Regulatory requirements

None at present.

5.10.8 References

CIBSE TM59 Design methodology for the assessment of overheating in homes. 2017
www.cibse.org/knowledge/knowledge-items/detail?id=a0q0O00000DVrTdQAL

GUIDANCE ON DETAILED BPE TECHNIQUES

5.11 DETAILED OCCUPANT FEEDBACK EVALUATION

Following core BPE user surveys and informal interviews with residents and other users, and alongside the findings from other BPE techniques, the BPE team may determine that more detailed investigations of occupant feedback would be beneficial or event required.

A number of methods are available; all require a lot of care and experience to ensure that privacy and ethical considerations are properly addressed, and that the methods are robust and unbiased.

Only a very brief overview is provided here. For more information and guidance, a very useful reference is Housing Fit for Purpose, by Fionn Stevenson, 2019.

The first step would usually be to carry out include **interviews and focus groups**, with questions informed by issues unearthed through the initial BPE.

In addition to guidance in the above book by Fionn Stevenson, and for elderly housing in particular, BPE teams may find the EVOLVE Toolkit useful: www.housinglin.org.uk/Topics/type/EVOLVE-Tool-Evaluation-of-Older-Peoples-Living-Environments/. Developed by the University of Sheffield, with PSSRU, University of Kent and supported by the Housing LIN, EVOLVE is a tool for evaluating the design of housing for older people. It is used to assess how well a building contributes to both physical support of older people and their personal well-being.

If needed, this can be followed by even more detailed studies including:

- comfort surveys
- usability surveys
- occupancy monitoring and analysis
- ethnographic studies.

There is free Usability Tool available: https://sites.google.com/view/bpe-poland/bpe-poland/bupesa-project/tools. It recommends the following eight criteria to cover in order to understand whether homes are usable or not:

- clarity of purpose
- location
- understanding the operation
- ease of use
- labelling
- feedback
- fine-tuning
- understanding of the need for interaction

Illustration of usability review: evaluation of an MVHR unit

Description and location
Greenwood Filters within MVHR unit

Usability criteria	**Poor**				**Excellent**
Clarity of purpose	■				
Intuitive switching	■				
Labelling and annotation	■				
Ease of use		■			
Indication of ystem response	■				
Degree of fine control	■				

Comments: No labelling whatsoever - if you are not familiar with the unit you don't know they are there. The filters are easy to take out and clean but some units clash with the door frames. There is little indication of when they are getting clogged up - a warning light might be useful? The whole front panel must come out to access the heat exchanger filter every two years - this operation in some units on site is very difficult due to clashes with doorframes and very poor location of units high up in narrow spaces.
(*Source: Fionn Stevenson, Housing Fit for Purpose, 2019)*

These additional investigations may be more useful if conducted in parallel with other detailed BPE techniques, depending on the issue of concern e.g. overheating modelling to delve deeper into causes and remediations for comfort, IEQ monitoring if there are indications that certain pollutants may be related to feedback such as recurring headaches or respiratory issues etc.

SECTION

06

INNOVATIVE BPE TECHNIQUES

INNOVATIVE BPE TECHNIQUES

6.0 INNOVATIVE BPE TECHNIQUES

This section covers techniques which are not included in the main BPE techniques as they are not yet independently assessed and/or commercialised and/or widespread enough to find people to apply them, however they offer promising potential and could become much more common in the near future.

6.1 AIRTIGHTNESS TESTING: LOW-PRESSURE PULSE TESTS

In recent years, an alternative to the airtightness blower door test method, the "LPP - low pressure pulse", or "pulse" method, has evolved. Rather than being carried out under pressure (50Pa), the test is carried out under pressure levels (4Pa) more representative of conditions likely to be experienced routinely in homes. The test system releases a measured amount of air from a portable compressed air receiver into the building, generating a flow rate through the gaps and cracks in the building envelope. The change of internal pressure in the building due to this flow is seen as a pulse. The rates of increase and decay in the building's pressure are used to measure the airtightness.

The benefits of low-pressure pulse tests compared to the fan pressurisation method are that the results are more representative of normal conditions in the 1-10Pa range, under as-inhabited conditions (including background ventilation conditions etc). Furthermore, the test is less disruptive as it does not need extensive pressurisation and blocking of all air inlets/outlets, and can be carried out in a short period of time.

On the other hand, it cannot be used for identification of leakage paths as a pressurisation / depressurisation test allows through the use of smoke.

Because pulse tests are much less disruptive than blower door tests, a potential benefit they offer is to carry out testing during construction to get an indication of whether construction is on track. A limitation then remains that, if poor airtightness is found, other methods have to be applied to identify leakage paths.

There is currently no standard methodology, but this is being examined as part of a consultation on the future of Part L and CIBSE TM23. It is therefore not included as part of the core BPE package, but this may change in the near future.

Home Grown Homes – Pentland Close:
Pulse test being carried out by Build Test Solutions

INNOVATIVE BPE TECHNIQUES

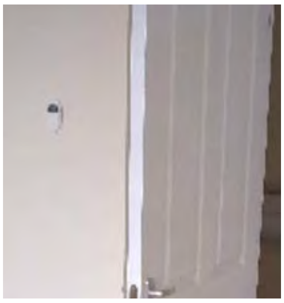
6.2 HEAT LOSS COEFFICIENT: USE OF SMART METER DATA

Due to the limitation of traditional co-heating tests, a number of methods are being developed to estimate the Heat Transfer Coefficient (HTC) of dwellings based on measured in-use energy consumption, allowing tests to be carried out when buildings are occupied at no disruption to occupants.

These tests use energy consumption data logged regularly (e.g. every 30 minutes), together with external weather data. The data is then examined via an algorithm to estimate the HTC.

Some of the methods also require, or can incorporate, additional information such as measurements of internal temperature, type of ventilation system, occupancy patterns, and basic property information (floor area, heating type, property type etc). Broadly speaking, the more information the algorithm incorporates, the more accurate the method is expected to be, but it also has less ability to be quickly and easily rolled out across the building stock. The methods are particularly appealing with the roll-out of smart meters but measurement can also be taken from homes without smart meters.

A number of methods (6) are currently the subject of trials supported by BEIS, which are due to report in 2021. Details and updates on these trials are available from the government website: ***Here.*** Some methods are already commercially available e.g. Purrmetrix, SmartHTC.

	Design (estimated by SAP)	Measured
Total HTC (W/K) (ventilation systems on)	42	Co-heating test: 46 ±9 SmartHTC: 40 ±6

Home Grown Homes – Croft Court - One of the methods being tested by the BEIS trials, SmartHTC, was used at Croft Court. It relied on the use of smart meters, and the installation of temperature sensors in every room (including the kitchen and bathroom), along with external temperature monitoring. Temperature readings were taken from 30th March to 24th April (typically, it would be better to measure some time between October and March, to maximise temperature differences with the outside and limit the impact of solar gains on readings.

SmartHTC can be used in occupied homes, but in this case it was carried out before occupation.

(Left) Temperature sensors were placed in every room, and used alongside the home's meters.

(Right) Comparison of HTC obtained from smartHTC with co-heating test result, and with design target. Contrary to usual practice in co-heating tests, where ventilation openings are usually sealed and systems off, in this case the systems were left operating to reflect the building's actual performance when occupied. The results show that the building's fabric performance was close to remarkably close to design estimates. The results of the co-heating test and SmartHTC agreed closely, within the combined uncertainty ranges of the tests.

Source: photos and information courtesy of Build Test Solutions, developers of SmartHTC

In the meantime, there are no established methodologies and few have been commercialised and independently assessed with publically available results. In particular, there are concerns about their accuracy for HTC estimates in new buildings with very good fabric performance, as relatively speaking the influence of other parameters on energy consumption (e.g. internal gains for occupants and equipment) becomes more significant, so the relative error on the HTC is likely to be larger (see for example Li M., David Allinson D. Lomas K., *Estimation of building heat transfer coefficients from in-use data Impacts of unmonitored energy flows*, International Journal of Building Pathology and Adaptation, 2019).

They are therefore not recommended here at this stage, but some may be in the near future, once the outcome of the BEIS trials is available and public. Subject to the outcomes of these trials, non-disruptive HTC measurements based on metered data could then become much more accessible and a useful part of the core BPE exercise.

6.3 HEAT LOSS COEFFICIENT: DYNAMIC / FAST CO-HEATING TESTS

Due to the limitation of traditional co-heating tests, a number of methods have been developed which are similar to the "standard" co-heating test, but carried out over much shorter periods and dynamic e.g. QUB, P-STAR.

QUB has been patented since 2012. It uses electrical heating to increase the temperature in the building and then allows it to cool over 2 periods after sunset. Power input is monitored along with internal and external conditions to calculate a global heat loss figure.

In the P-STAR methodology, three internal conditions are created, one heating period (16 hours), one cooling down period (16 hours) and finally a heating period. Power input, internal and external environmental conditions are measured during these periods. Using this dynamic pattern, an estimate can be made of the HLC of the building alongside the thermal mass levels.

These methods are not standardised, although there are efforts in academia and European standardisation committees which may lead to standards in the future.

They are typically not yet commercialised, although this may change in the near future. Veritherm, the result of a partnership between Redbarn Group and Cambridge Consultants, filed in a patent for its algorithms. The product is to provide HTCs based on overnight heating and cooling of the building.

As a result, they are not currently recommended in this guidance document, as core part of the BPE exercise, although some BPE teams may find them useful, for example in collaborations with academia.

SECTION

07

DEFINITIONS

DEFINITIONS

7.1 SAP

SAP is the methodology used to demonstrate compliance with Part L1A of the UK Building Regulations. It is a monthly steady-state method, and uses standardised occupancy and behaviour assumptions to estimate a home's energy performance (for space heating, domestic hot water, lighting and ventilation) and consequent carbon emissions per unit floor area. SAP includes a minimum Fabric Energy Efficiency Standard (FEES) which limits the total fabric heat loss from a home, and a crude assessment of the overheating risk. The SAP methodology is also followed to produce Energy Performance Certificates (EPCs) required when a home is complete and sold.

It is not recommended that targets are set based on SAP calculations, as the SAP methodology is designed and intended as a compliance tool not an accurate prediction for ultimate energy consumption.

With reference to SAP calculations each assessed unit should receive a compliance report which demonstrates a pass by showing that

1 The predicted Building Emissions Rate (BER) is lower tha the Target Emissions Rate (TER)
2 The Dwelling Fabric Energy Efficiency (DFEE) is lower than the Target Fabric Energy Efficiency (TFEE)
3 The summertime overheating risk is low.

7.2 THERMAL BRIDGES

There are two main types of thermal bridges in buildings; repeating and non-repeating:

- Repeating thermal bridges occur regularly within a typical dwelling; for example, where timber studs bridge a layer of insulation in a cavity wall. These are taken into account in the 'U-value' calculation (a measurement in m² of the effectiveness of a material as an insulator).
- Non-repeating thermal bridges occur at junctions between building elements and around openings, these are measured as Psi (Ψ) values (linear thermal heat transmittance). The Psi values are accounted for in the SAP calculation.

The sum of all the non-repeating thermal bridges within a home forms the overall Y-value (W/m²K). This Y-value that is used within the SAP calculation, with the external fabric U-values to estimate the total heat loss for the home.

7.3 HEAT TRANSFER COEFFICIENT (HTC)

The HTC is defined in BS EN ISO 52016:2017 as the heat flow rate from the internal air mass to the surrounding external environment divided by the indoor-outdoor air temperature difference (by convention Tindoor minus Toutdoor, i.e. the direction of heat transfer is from inside to outside). It is the sum of the transmission HTC, i.e. the heat flow rate due to thermal transmission through the fabric of a building, divided by the difference between the environment temperatures on either side of the construction", and of the ventilation HTC, i.e. the heat flow rate due to air entering an enclosed space either by infiltration or ventilation, divided by the difference between the internal air temperature and the supply air temperature" (as defined by BS EN ISO 13789:2017).

However, co-heating tests are usually performed to assess building fabric performance, so they are performed with ventilation systems off and inlets and outlets sealed, in order to take account of heat loss through transmission and infiltration, but not through purpose ventilation.

This approach may change in the future, with tests become more widespread which rely on metered data in occupation and, sometimes, take account of purpose ventilation - see > ***section 6.2***.

ACRONYMS

8 ACRONYMS

ACD	Accredited Construction Details
BPE	Building Performance Evaluation
CLT	Cross Laminated Timber
FM	Facilities Manager / Management
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
MVHR	Mechanical Ventilation with Heat Recovery
PC	Practical Completion
POE	Post Occupancy Evaluation
PVs	Photovoltaic
VOC	Volatile Organic Compounds

TOOLPACK

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

BPE PROJECT TIMELINE

For further information:
https://woodknowledge.wales

BRIEFING & EARLY DESIGN

Define performance objectives – > ***Client sheet***

Identify relevant BPE lessons from past projects

Visit the site, ideally with future inhabitants

Use BPE lessons from past projects to inform the proposals

DESIGN DEVELOPMENT

See Design Stage sheet

- [ ] Site visit if possible, ideally with residents
- [ ] Design and documentation review
- [ ] Handover review
- [ ] Commissioning review
- [ ] Early stage overheating analysis
- [ ] Energy strategy review
- [ ] Airtightness review
- [ ] Thermal bridging and moisture review
- [ ] Acoustic review

Gather BPE lessons for future projects

If possible on larger projects, use BPE lessons from early phases to inform later stages of design and construction

IN CONSTRUCTION

See Construction Stage sheet

- [ ] Design and documentation review
- [ ] Handover review
- [ ] Site inspections and spot checks
- [ ] Airtightness checks and preliminary tests, and monitor change
- [ ] Commissioning
- [ ] Acoustic checks and testing of ventilation system
- [ ] Early stage overheating analysis – monitor change
- [ ] Energy strategy review – monitor change
- [ ] Thermal bridging and moisture inspections, and monitor change
- [ ] (if possible – Thermography spot checks)

Gather BPE lessons for future projects

If possible on larger projects, use BPE lessons from early phases to inform later stages of design and construction

COMPLETION & HANDOVER

See Completion & Handover Stage sheet

- [ ] Design and documentation review
- [ ] Handover review
- [ ] Site inspection and spot checks
- [ ] Airtightness test
- [ ] Commissioning, and plan for seasonal commissioning if required
- [ ] Acoustic checks and testing of ventilation system
- [ ] Early stage overheating analysis – record final, monitor change
- [ ] Energy strategy review – record final, monitor change
- [ ] Thermal bridging and moisture – record final, monitor change
- [ ] (if possible – Thermography spot checks)
- [ ] Put things are in place for in-use BPE: metering and monitoring systems, permissions and engagement from inhabitants and other users etc.

Gather BPE lessons for future projects

IN USE

See In Use Stage sheet

- [ ] Design and documentation review
- [ ] Handover review
- [ ] Review of design strategies: energy strategy, overheating risk, thermal bridging and moisture
- [ ] Site visit, if at all possible with inhabitants
- [ ] Airtightness re-test
- [ ] Commissioning review and recommissioning if required
- [ ] Acoustic checks and re-testing of ventilation system if required
- [ ] Energy use audit
- [ ] Water use audit
- [ ] Survey of inhabitants and other users
- [ ] (if possible – Thermography spot checks)
- [ ] (if possible – IEQ spot checks)
- [ ] **Making sense of it all:** Analyse BPE results altogether, to gain a holistic view of building performance
- [ ] **BPE reporting:** BPE techniques applied
- [ ] Results against initial objectives, regulations and best practice
- [ ] Overall building performance, what seems to work well and not
- [ ] Recommended next steps: interventions (if any), detailed BPE (if any)
- [ ] Lessons learnt

Gather BPE lessons for future projects

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

CLIENT SHEET

Project Name:

Date:

For further information:
https://woodknowledge.wales

OBJECTIVES	TARGETS	Targets set? (tick boxes)	Target details	Results details
Inhabitants				
To not overheat	**OVERHEATING:** GHA tool to evaluate overheating risk level (Low/Med/High)	☐		
	CIBSE TM59 or other target	☐		
To keep warm in winter	See **ENERGY AND FABRIC PERFORMANCE**			
To have good daylight	**DAYLIGHT:** daylight factor/uniformity ratio etc	☐		
To be quiet inside	**ACOUSTIC COMFORT:** Do noise conditions on site (day and night) require an acoustic survey?	☐		
	Noise from HVAC services (dBA)	☐		
	Acoustic separation between adjoined units (dBA)	☐		
To have good air quality	**INDOOR AIR QUALITY:** Check design meets Building Regulations Part F v for background AND purge ventilation rates	☐		
	Indoor pollutant targets e.g. Max. VOC levels, formaledehyde (mg/m³) or CO_2 (ppm)	☐		
To be mould/rot free	**MOISTURE CONTROL:** establish approach (permeable/not) and how timber elements will dry	☐		
	Set design moisture levels for major timber elements	☐		
User satisfaction	Commit to evaluating the satisfaction and comfort of inhabitants and, if applicable, other users e.g. facilities management team	☐		
Energy To minimise use	**ENERGY PERFORMANCE:** total energy consumption (kWh/m²/yr, kWh/ dwelling/yr); space heating demand; Passivhaus certification	☐		
	On-site renewable energy generation (in addition to building performance consumption target)	☐		
	Associated metering and monitoring strategy	☐		
	FABRIC PERFORMANCE: Air tightness target (m³/hr/m²@50Pa or ach)	☐		
	Minimise thermal bridges e.g. Y-value per unit (W/m²K)	☐		
	Maximum Ψ value for all thermal bridges (W/mK)	☐		
	Heat Loss/Heat Transfer Coefficient (W/K) & form factor	☐		
Water To minimise water use	**WATER CONSUMPTION:** (l/person/day)	☐		
BESPOKE TARGETS:	e.g. embodied carbon, social value	☐		

EVALUATION

Relevant BPE techniques & guidance

< DESIGN AND DOCUMENTATION REVIEW, HANDOVER REVIEW >

< SITE VISITS AND INSPECTIONS >

< COMMISSIONING AND PERFORMANCE TESTING >

< ASK INHABITANTS - SIMPLE USER SURVEY >

OVERHEATING
Overheating check

ACOUSTICS
Acoustic review, checks and tests

MOISTURE
Thermal bridging and moisture review

ENERGY STRATEGY
Energy strategy review

ENERGY USE
Simple energy use audit

AIRTIGHTNESS
Airtightness testing during construction and post-completion

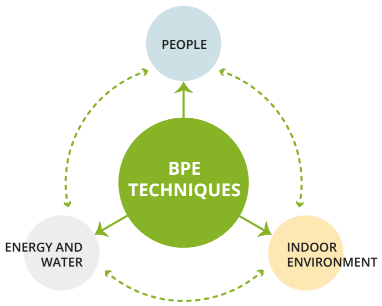
WATER USE AUDIT
Simple water use audit

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

MAKING SENSE OF IT ALL:

Using BPE techniques to gain a holistic picture of building performance

For further information:
https://woodknowledge.wales



PEOPLE

- Direct user feedback
- Site observations and indications on user satisfaction with the operation of the building and its systems, and with the indoor environment

How are occupancy patterns and behaviour likely to affect energy consumption?

e.g. appliances, operation of windows and ventilation systems, occupancy density and hours etc

How do building and systems performance affect in occupant feedback?

e.g. winter and summer thermal comfort, noise from outside and from ventilation systems, perceived air quality, complaints about energy costs and risk of fuel poverty

How is IEQ affecting feedback from occupants? Are quantitative measures and qualitative feedback consistent with each other, and what may this indicate?

e.g. Comfort: feedback of summer discomfort but reasonable air temperature measurements: are there sensitive individuals? High humidity levels? Radiant discomfort from large glazed areas? Little air movement through limited openings ? How does this compare with the early stage overheating analysis?

e.g. Air quality: feedback on headaches vs measured formaldehyde levels, feedback on stuffiness vs CO_2 levels, feedback on dry air vs humidity levels ?

Are there causes for concerns about pollutant levels which occupants should be made aware of?

How may occupancy patterns and behaviour affect IEQ?

e.g. high washing / bathing impacting humidity levels; high occupancy affecting humidity and CO_2 levels; have occupants modified the intended operation of ventilation systems?

BPE techniques

Design and documentation review
Commissioning
Handover review
Site visits

Energy strategy review
Airtightness review, site checks and tests
Thermal bridging & moisture review and checks
Early stage overheating analysis (GHA)
Acoustic checks & testing of ventilation system
(Thermography spot checks)
(IEQ spot checks, short-term monitoring)

Energy use audit

Water use audit
User surveys

ENERGY AND WATER

- Metered data on energy and water use
- Physical (qualitative and quantitative) measurements of the performance of fabric and systems
- Site observations and indications on occupancy, behaviour, and the operation of the building and its systems, which may affect energy performance

Are there signs that building design, installation or operation may affect both energy consumption and indoor environment i.e. the operation of ventilation systems leading to energy inefficiencies, noise and poor air quality?

e.g. poor airtightness leading to pollutant ingress, draughts, and high energy use for heating; poor thermal bridging details leading to heat loss as well as condensation and mould growth?

INDOOR ENVIRONMENT

- Physical acoustic measurements (+ possibly IEQ)
- User feedback on perceived IEQ
- Site observations on perceived IEQ: BPE team's own perceptions, and indications of user interventions related to noise, air quality, thermal comfort, daylight and glare

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

CORE BPE TECHNIQUE

For further information:
https://woodknowledge.wales

CORE BPE TECHNIQUE	WHEN CAN THE BPE TECHNIQUE BE APPLIED ?				WHAT PERFORMANCE OBJECTIVE DOES THE BPE TECHNIQUE HELP WITH?			DOES IT NEED AN EXPERT?	COST & TIME
	Design	In construction	Completion & handover	In occupancy	Energy & Water	IEQ	People		
Design & documentation review	✓	✓	✓(be aware to distinguish BPE from official PC sign-off)	✓	✓	✓	✓	No, but BPE experience is useful	£
Handover review	✓	✓		✓	✓	✓	✓		£
Site visits and inspections	✓if possible, ideally with residents	✓		✓	✓	✓	✓		£
Commissioning	✓	✓	✓	✓	✓	✓	✓	Yes - commissioning engineer	£-££
Energy strategy review	✓	✓	✓	✓	✓		✓(fabric first approach helps comfort)	No, but BPE experience is useful	£
Early overheating analysis	✓	✓	✓	✓	✓(overheating may lead to energy use for cooling)	✓	✓		£
Acoustic review, checks and tests	✓	✓	✓	✓	-	✓	✓	Yes - acoustician	£ £
Fabric Airtightness review, checks and testing	✓	✓	✓	✓	✓	✓	✓	Yes, for blower door test or low-pressure pulse test	£-££
Fabric Thermal bridging and moisture review and checks	✓	✓	✓	✓	✓	✓if severe e.g. mould growth, condensation	✓if severe and noticeable e.g. mould growth, condensation	Yes - someone experienced in thermal bridge analysis	£
Energy use audit	-	-	-	✓	✓	✓	✓especially. for residents in fuel poverty	No, but BPE experience is useful	£-££ depending on number of homes & metered data quality & quantity
Water use audit	-	-	-	✓	✓(hot water)	✓	✓e.g. poor quality fittings may be frustrating or get replaced		£
User surveys	-	-	-	✓	✓(poor usability may affect energy consumption)	✓(beware perceptions cannot be relied on for air quality)	✓	No, but BPE experience is useful	£ £

Generally speaking, the only Core BPE techniques which require an expert and are more expensive are those which are also linked to regulatory requirements; additional BPE costs may therefore actually be limited to doing it properly, not the full costs of that technique. The exception is for user surveys: this will vary with the number of homes, type of survey used, extent of time spent on site with residents to accompany the surveys etc; in addition, someone with BPE experience is recommended for depth of analysis and to liaise with residents sensitively.

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

PROJECT STAGE PROMPT SHEET

DESIGN

For further information:
https://woodknowledge.wales

EMBEDDING PERFORMANCE IN THE DESIGN AND TEAM CULTURE	
Performance objectives	☐ What are the performance objectives (energy, water, people, others), and are they clear? How have they been recorded and communicated to the team? How do they compare with regulatory minima and best practice? See > ***Client sheet*** ☐ Overall, is there evidence these objectives have been incorporated in the design proposals? See > ***Design review***
Early in the design	☐ Is there a plan for BPE activities, and who will carry them out, with appointments in place? ☐ If the airtightness target is onerous (e.g. Passivhaus or equivalent), is an airtightness champion appointed?
Holistic design	☐ Carry out regular (at least at each RIBA checks) on the design, how it works together and how it compares with performance objectives – see list of BPE activities at this stage ☐ Have relevant project precedents been identified, especially those with BPE to identify performance issues, and lessons incorporated in the design?
Taking users into account	☐ Have future inhabitants and other users (including FM and building management teams) been given the opportunity to visit the site with the design team, or are there plans for this to happen? ☐ Have they had an opportunity to express what they want (e.g. workshop with the design team), and to comment and input into the performance objectives and design proposals? This is a good opportunity to embed sustainability objectives into the project. During the design development, what is the process for keeping them informed and involved with changes which could impact them? An early draft of the Building User Guide is useful for future users to comment on the format, outline content, and language, and an opportunity for the team to explain proposals clearly and to test whether they could work for future users ☐ If future residents and other building users are not known at this stage, what is the process for taking user considerations into account e.g. user representative? Learnings from other schemes?

EMBEDDING PERFORMANCE IN THE DESIGN AND TEAM CULTURE	
Preparing for construction	Before start on site, check the following is in place, to deliver performance and facilitate in-construction BPE: ☐ Performance objectives are incorporated into the tender packages, and associated design checks and calculations (e.g. energy review, overheating risk review etc.) ☐ Construction team are aware of the performance objectives and of best practice procedures to follow ☐ Clear and agreed plan for in-construction BPE, with associated appointments, programme, resources and training ☐ Have the team identified design features which, based on past lessons, are likely to need careful follow-up during construction and handover e.g. complex systems; relatively new solutions to the wider industry or to the project team?
Preparing for handover	☐ Handover may seem a distant event during the design stage, but in fact the plans for handover and associated documentation should start being prepared at the design stage, including a dedicated period in the programme for handover activities and an agreed format and outline content for the Building User Guide – see > ***handover review***, and "taking users into account" above
Preparing the future BPE	☐ Have a plan for the in-use BPE stage: ideally, a scope of BPE activities to be carried out at the in-use stage, and who will carry them out; if future users are known, arrangements could start being put in place to explain to them the benefits of BPE, what it would entail, and check privacy and ethics implications ☐ Does the design allow in-use BPE? Have the requirements for future in-use monitoring been discussed and incorporated in the specifications, including the level of sub-metering and associated capability (logging, remote reading etc)? – see > ***design review***:

BPE ACTIVITIES AT THIS STAGE

- ☐ Design & documentation review
- ☐ Handover review
- ☐ Commissioning review
- ☐ Energy strategy review
- ☐ Airtightness review
- ☐ Thermal bridging & moisture review
- ☐ Early stage overheating risk analysis
- ☐ Acoustics review

BPE LEARNING LOOPS

☐ Identify and record BPE lessons from this stage. For example, this could be an early stage design decision (e.g. single-aspect building layout, highly glazed façade) which was flagged up in the design checks to create performance issues such as energy consumption and overheating risk, and which subsequently needed substantial amendment.

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

PROJECT STAGE PROMPT SHEET

IN CONSTRUCTION

For further information:
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EMBEDDING PERFORMANCE IN THE CONSTRUCTION PROCESS AND TEAM CULTURE

Performance objectives

- ☐ Are the whole team aware of performance objectives?
- ☐ Have the team been provided with appropriate induction and training? In particular, have site teams, including sub-contractors, received inductions and training on best practice construction for airtightness, including installation as well as storage?

Before start on site

Programme – is it in line with BPE plans and performance objectives?

- ☐ Is it in line with the sequencing strategy agreed before start on site to achieve the targeted airtightness? Is it clear when inspections of the thermal and airtightness lines, and preliminary and final airtightness tests will be carried out?
- ☐ Is there an allocated period for commissioning, in line with good practice and the original programme?
- ☐ Is there a buffer period identified for remediation / changes if required, and an agreed strategy in case of test failure or delays? Ideally this should include identifying opportunities for early inspections and checks e.g. inspections of construction details and commissioning of ventilation system on an early dwelling before roll-out across the scheme
- ☐ Is there a suitable period for handover?

BPE scope and appointments

- ☐ Are all appointments in place for BPE activities throughout construction? This should include: contractor and sub-contractors; design team members for input to final design, monitoring of changes and site inspections; BPE site visits, inspections and testing (e.g. early airtightness testing, construction details to minimise thermal bridging); commissioning; additional appointments if required e.g. clerk of works
- ☐ Is there an airtightness coordinator, or "champion"? This is recommended if the target is onerous e.g. Passivhaus.

Checking the installation is as intended

See > ***site inspections – in construction***
Change management: If design issues that are still being detailed, or if changes and substitutions occur, their possible impact on building performance should be assessed, including a review of performance objectives. A revisit of the design checks is then useful (i.e. > **design review, airtightness review, overheating review, thermal bridging** and **moisture review**)

Taking users into account

- ☐ Have future inhabitants and other users (including FM and building management teams) been given the opportunity to visit the site?
- ☐ What is the process for keeping them informed and involved with changes which could impact them?
- ☐ Is there a draft of the Building User Guide? Have future inhabitants, FM and building management teams had an opportunity to comment?

PREPARING THE NEXT STAGE

Preparing for handover

- ☐ see > ***Handover review***

Preparing the future BPE

If possible, start to put in place the plans for the in-use BPE stage:

- ☐ Which BPE tests will be carried out, and who will carry them out
- ☐ Arrangements with future residents and other building users

BPE ACTIVITIES AT THIS STAGE

- ☐ Design & documentation review
- ☐ Handover review
- ☐ Site inspections and spot checks
- ☐ Airtightness checks and tests
- ☐ Commissioning
- ☐ Acoustic checks and tests
- ☐ Review implementation, record and monitor change: energy strategy, thermal bridging and moisture, overheating

BPE LEARNING LOOPS

- ☐ Identify and record BPE lessons from this stage. For example, this could be a design detail making airtightness inspections and remediations more difficult.

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

PROJECT STAGE PROMPT SHEET

COMPLETION & HANDOVER

For further information:
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CHECKING PERFORMANCE OBJECTIVES HAVE BEEN IMPLEMENTED DURING DESIGN AND CONSTRUCTION

Performance objectives

- ☐ Check and record test results vs performance objectives (see > ***client sheet***).
- ☐ Note - It is important not to confuse the BPE exercise with the formal signoff process and regulatory checks: BPE checks have a specific focus, and do not negate the need for the formal approval process, which should be covered by dedicated appointments.
- ☐ Pay particular attention to the airtightness test and commissioning, as these are essential elements which affect all aspects of performance including energy use, comfort, and air quality. Airtightness is also a good indicator of overall build quality.

Additional actions and remediations

- ☐ Apply remediation before Practical Completion wherever possible, as the focus of teams tends to move away from the project afterwards; where this is not possible, agree whether remediation will be part of the defects list, who will carry it out, and timescales
- ☐ If seasonal commissioning will be required, include it in appointments and the programme, and inform users of why it is beneficial

Taking users into account

- ☐ Is all handover information ready and satisfactory, and have future residents and other building users had the opportunity to comment and confirm it meets their needs?
- ☐ Have site visits and inductions been carried out with future residents and other building users?
- ☐ See Review of handover processes and documentation Have future inhabitants and other users (including FM and building management teams) been given the opportunity to visit the site?

PREPARING THE NEXT STAGE

Preparing the future in-use stage and BPE

- ☐ Are all systems which will be used in the BPE activities (e.g. meters, sensors) commissioned?

Put in place the detailed plan for in use BPE:

- ☐ Scope of BPE activities, who will carry them out, and when
- ☐ Arrangements with users – timing and access, clear proposals for what will be done and the implications it will have for them (time, disruption, installation of equipment etc) as well as the benefits they can gain from it (e.g. opportunity to feedback on what doesn't work, or to get additional support if things are too complex), ethics and privacy approval.

BPE ACTIVITIES AT THIS STAGE

- ☐ As-built design & documentation review
- ☐ Review of handover process and documentation
- ☐ Site inspection and spot checks
- ☐ Airtightness test
- ☐ Commissioning
- ☐ Acoustic checks and testing of ventilation system
- ☐ Review of strategies against as-built state: Early stage overheating analysis, energy strategy, thermal bridging and moisture – record final, monitor change

BPE LEARNING LOOPS

- ☐ Identify and record BPE lessons from this stage. For example, this could be the ventilation design making measurement of air flow and commissioning more difficult.

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

PROJECT STAGE PROMPT SHEET

IN USE

For further information:
https://woodknowledge.wales

EVALUATING OVERALL BUILDING PERFORMANCE

Performance objectives	☐ Record any performance objectives set for the project - see > ***client sheet*** ☐ Check and record results of BPE tests against performance objectives (if applicable). **Note** - It is important not to confuse the BPE exercise with the snagging and defects period: BPE checks have a specific focus, and do not negate the need for formal processes, which should be covered by dedicated appointments. This is also why it is useful for the in-use exercise to take place after the first year of occupation, to distinguish it with a clear focus on in-use performance.
Before any in use BPE	☐ Ensure agreements are in place with inhabitants and other users, taking account of privacy and ethics and ensuring they understand the implications e.g. equipment, time, disruption etc ☐ Ensure any installed meters and sensors to be used in the BPE are commissioned – as a very minimum, this should cover the mains energy and water meters; ideally, sense checks on the monitored data could be done before the in-use BPE exercise proper, to make sure the data will be reliable enough. This should not be neglected and can take time.
Taking users into account	☐ See agreements, privacy and ethics above ☐ Involve inhabitants and other building users as much as possible in the BPE exercise: this should include the feedback surveys, but also site visits and informal interviews at that time, if they agree. They will be invaluable sources on information and insights on how well the homes work.
Making sense of it all	☐ Review BPE results against performance objectives, good practice, and regulatory minima. Ideally, this should include a comparison of how objectives and BPE results evolved from the briefing stage, specifications, as-built tests (if available), and the in-use BPE tests: this can give a good indication of how much importance was given to performance and how well it was embedded in the project. Pay particular attention to the airtightness test and commissioning, as these are essential elements which affect all aspects of performance including energy use, comfort, and air quality. Airtightness is also a good indicator of overall build quality. ☐ It is essential to review results from all the BPE techniques together, in order to build a holistic image of building performance and start to identify possible causes and solutions: conclusions based on the results from a single BPE technique should generally be treated with a lot of caution - See diagram > ***making sense of it all***

REPORTING ON BPE

The BPE report should include the following:

- ☐ a brief description of the project, building, and its context
- ☐ Key findings: overall performance in each aspect (people – satisfaction and comfort, IEQ, energy, water, fabric); what works well, what less so
- ☐ Possible causes for under-performance and possible improvement measures
- ☐ Recommended detailed BPE as a next step, why, what it could bring
- ☐ Other recommended next steps, if relevant. For example, this could include recommissioning, additional training to residents, a revised Building User Guide. Note that substantial interventions on the building are not recommended as a result of core BPE alone, unless the issue that needs addressing has very clear reasons and solutions. Usually, a more detailed investigation would be required.
- ☐ Lessons for future projects
- ☐ Give sufficient time and opportunities for the client and the residents and building users to comment on the report before final versions, and to confirm they are happy with the information included, including confidentiality and privacy issues

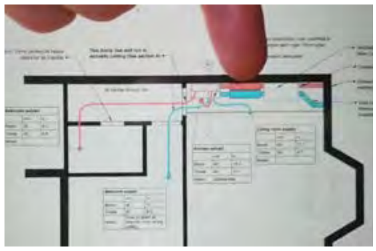
BPE ACTIVITIES AT THIS STAGE

- ☐ Site visits – home tour, ideally with inhabitants and with a simple photographic survey.
- ☐ Design and documentation review
- ☐ Handover review
- ☐ Review of design strategies: energy strategy, overheating risk, thermal bridging and moisture
- ☐ Airtightness re-testing
- ☐ Commissioning review and re-commissioning if required
- ☐ User surveys (i.e. inhabitants but also FM, building manager and others if relevant)
- ☐ Energy use audit
- ☐ Water use audit
- ☐ Acoustic checks and re-testing if required

BPE LEARNING LOOPS

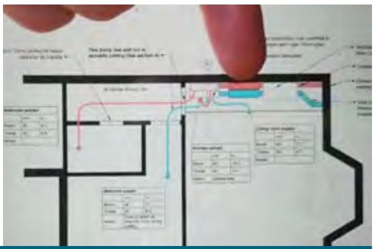
- ☐ Identify and record BPE lessons from this stage. There should be plenty of them, covering all aspects of building performance (energy, people, indoor environmental quality), and ranging from design issues, procurement, through to construction, or about the BPE activities themselves.

DESIGN AND DOCUMENTATION REVIEW



CORE BPE TECHNIQUE	
Applicable performance objective and target	All.
Why do it i.e. where it adds value, what it can help with	A design and documentation review helps to assess how building performance is embedded in a project, from the overall strategy to individual design elements. At the design stages, it can help identify changes which would benefit performance. In use, it can help identify problems and potential causes and remediation, often before even visiting a building or receiving feedback.
When to do it	It is useful to have building performance as standing item on meeting agendas; in addition, formal reviews should happen ideally at each RIBA stage, before sign-off, to embed building performance. Reviews evolve as the project progresses, starting with strategic issues such as elevations, site and building layout, and moving to details and change management in later stages. In-use: to contribute to the overall evaluation of performance.
How to do it Tips and tricks	The review should at the minimum include the following: ☐ Outline brief and performance objectives, with a holistic view: energy and carbon, people, and indoor environmental quality ☐ Key drawings for the home or a typical home in the scheme ☐ Energy & sustainability strategy, systems, controls, metering. Consider not only the design proposals, but also their operational and maintenance implications, how users have been considered and involved, and whether the design took account of past projects and BPE lessons – this would be a very positive sign. See prompts below for issues to look at. More detailed design checks should be carried out alongside: ☐ > Core BPE - ***Handover review*** ☐ > Core BPE - ***Energy strategy review*** ☐ > Core BPE - ***Thermal bridging and moisture review*** ☐ > Core BPE - ***Commissioning - design stage*** ☐ > Core BPE - ***Acoustic review, tests and checks*** ☐ > Core BPE - ***Airtightness review*** ☐ > Core BPE - ***Early overheating risk (Good Homes Alliance)***
Needs an expert?	No, but someone experienced in design and building performance.
Cost and time	£. Typically up to a day of the BPE team per review; the design team and possibly client should be involved at design stages.
Regulations	No.
Specific considerations for timber construction	Designing for moisture and airtightness; low-VOC specifications.
What to do with the results? i.e. how to interpret results & identify next steps (remediation or BPE)	Alongside other BPE techniques: picture of how well performance objectives were embedded in the project; identify elements that need resolving and/or detailing in the next stages; recommended changes for the project team to consider. **Possible detailed BPE as next step:** tbc with other BPE findings.

DESIGN AND DOCUMENTATION REVIEW



PROMPTS FOR QUESTIONS AND ISSUES TO LOOK AT

Note – this is not meant as design guidance, but to highlight key principles that the BPE and design teams should be aware of and raise at BPE design reviews to identify possible performance issues and facilitate future BPE. Additional issues will be identified on each project, for example through past BPE lessons.

Taking users into account

- [ ] Have future inhabitants and other users (e.g. facilities managers) been considered in the design? This could include their input directly if possible, via a user rep, or at the very least via past BPE lessons.
- [ ] If they are known, have they had the opportunity to comment on the scheme? Has their feedback been incorporated, or are there plans for this to happen?
- [ ] What is the strategy and type of controls (including lighting, temperature, and ventilation)? How easy and useful do they seem to be?
- [ ] **Ease of use and maintenance:** Do the proposals seem appropriate for the resources expected to be available once homes are occupied? Proposals should be very simple for individual homes without FM or management team, but even larger schemes may only have limited resources, so complexity should be avoided.

Designing for good Indoor Environmental Quality, health and comfort

- [ ] Do all habitable rooms have openable windows? What are the opening mechanisms? Are there security or health and safety implications, or other barriers to having windows open?
- [ ] Has there been a team discussion on the most appropriate ventilation strategy, considering air quality as well as energy efficiency? e.g. humidity control, provision of fresh air, outside air pollution, internal finishes.
- [ ] If mechanical ventilation is provided, do mechanical air inlets avoid sources of pollution e.g. from roof or courtyard side, rather than onto a busy road?
- [ ] If the site is exposed to pollution (e.g. most urban areas in the UK), is mechanical ventilation with a filter for fine particulates provided? Is this accounted for in energy calculations and ventilation design?
- [ ] Designing to limit overheating risk: see > ***Core BPE - Early overheating risk***
- [ ] Have general principles of designing for good daylight been incorporated? This should include, as very minimum:
    - [ ] Do proportions of glazing seem reasonable? Beware rooms where glazed areas are below 20% of the floor area, as this could be insufficient for good daylight; inversely, check that glazed areas are not excessive, as this could cause winter discomfort, heat loss, and summer overheating.
    - [ ] Position of glazed areas: glazing below sill height and in corners will contribute little to daylight, but contribute to heat loss and solar gains.
    - [ ] Types of window openings that consider ventilation (background, purge, and summer comfort), safety, security; interaction with shading devices.

Water strategy review

- [ ] Are the design and specifications in line with water performance objectives? This should be relatively simple, as efficient water appliances are becoming routine, but it is important to check their quality as otherwise they may be frustrating for users and even get replaced. Feedback from previous schemes is useful here, to identify appliances and fittings to select or avoid. Check consistency between architecture and engineering specs (e.g. fittings may be in the architectural package, and restrictors in the public health engineer's package).
- [ ] Water metering & monitoring: water meters should always be provided, and easily accessible for residents. For BPE, ideally they would have logging and remote monitoring capability. Water recycling systems should be submetered so their contribution can be established.
- [ ] Pay attention to complex systems with operational and maintenance implications e.g. greywater recycling, or rainwater recycling if other than a simple water butt. Make sure they are appropriate for the expected maintenance resources, and that future users are aware of it.

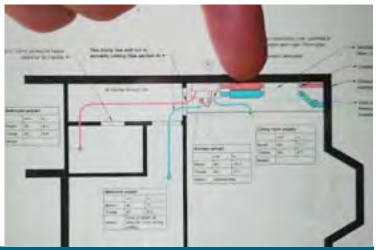
Overall performance, and how things work together

Are performance objectives clear and recorded? Depending on their appointment, the BPE team may highlight opportunities for improvements to targets or design assumptions, or where they may be over-optimistic.

Do the design and specifications overall reflect the objectives and/or best practice for energy, water, indoor environmental quality, and user comfort and satisfaction?

Do the design proposals work together as a whole, noting interactions between disciplines and building elements? Are assumptions and design proposals consistent with each other? For example, pay attention to assumptions on window openings in acoustic report, overheating risk assessment, architectural design, and engineer's ventilation assumptions

DESIGN AND DOCUMENTATION REVIEW

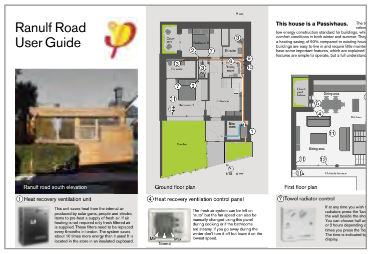


PROMPTS FOR QUESTIONS AND ISSUES TO LOOK AT (Cont.)

Embedding BPE and learning loops

- [ ] Have relevant project precedents and BPE been identified, and lessons incorporated? This can apply to the design proposals but also wider elements of the project, such as the procurement route or appointments.
- [ ] Have the team identified elements which, based on past lessons, are likely to need careful follow-up during the next design stage, construction, practical completion and handover e.g. complex systems; relatively new solutions to the wider industry or to the project team?
- [ ] Are there clear plans for BPE in construction and in use, and does the design allow this? In particular, have the requirements for in-use monitoring been discussed and incorporated in the specifications, including the level of submetering and associated capability (logging, remote reading etc)? This should include:
    - [ ] Energy metering and monitoring: see > ***Core BPE Energy strategy review***
    - [ ] Water metering and monitoring: see > ***water strategy review***.
    - [ ] Indoor Environmental Quality monitoring: What aspects need to be validated/verified by monitoring? This should consider the data that would be useful, how monitoring should be integrated in the design, or whether it can be addressed through bespoke equipment later on, as part of in-use BPE. For example, while temperature and humidity sensors are relatively common and cheap, they typically would not have logging capability, but this could be specified if the need is identified e.g. if there are concerns about fuel poverty and risks of under-heating, or concerns about overheating. Some projects may want to monitor other pollutants but this is less common and likely to be with a research outlook or specific to circumstances e.g. particulate matters to assess new filtering systems or if future inhabitants are known to be sensitive; formaldehyde to check the impact of low-VOC specifications on indoor air quality.

HANDOVER REVIEW



CORE BPE TECHNIQUE	
Applicable performance objective and target	All
Why do it i.e. where it adds value, what it can help with	The handover is often neglected due to programme and commercial pressures near project completion. It is essential to good performance and maintenance, and should include: ☐ Documentation on the home and how to operate it well, aimed at residents and other users (e.g. FM); the information should be complete, relevant, and easy to understand. ☐ The process itself including training and inductions.
When to do it	Handover itself occurs around practical completion (PC) but must be prepared during design and construction. A handover review is also useful in-use, to assess the support provided to users on how homes are meant to work. A poor handover could, at least partly, explain a lot of issues.
How to do it Tips and tricks	**Note** - It is important to distinguish the BPE handover review from the formal sign-off process and regulatory checks: BPE has a specific focus and does not replace the formal approval process. **Design stage:** ☐ Are there proposals for the format and content of the Building User Guide? Will future residents, FM and building management teams be given an opportunity to comment? Early drafts of the Guide are an opportunity to explain design proposals and get feedback from future users. ☐ What are the plans for handover? Do they include site visits and training? Will there be support (on or off site) for a period after completion? Are residents and other users satisfied with the plan e.g. would they like “live” inductions, not online? **Completion and handover stage, and in-use:** ☐ Are handover documents (including a simple Building User Guide) available at or near completion? Have residents and other users had the opportunity to comment before the final version? Are they even aware these exist (often not the case)? ☐ Do these documents seem complete, accurate, and easy to understand? Do they cover features which may be complex or unfamiliar (e.g. mechanical ventilation, thermal mass or movable external shading), or need maintenance (e.g. filters)? ☐ Was additional support available in a variety of methods for at least a few weeks or months around completion e.g. visits, training, online, recorded videos, support team on- or off-site?
Needs an expert?	No.
Cost and time	£
Regulations	O&M documentation.
Specific considerations for timber construction	–
What to do with the results? i.e. how to interpret results & identify next steps	tbc, depending on issues uncovered, but often will recommend better handover documentation and/or support to residents. **Detailed BPE as next stage:** n/a

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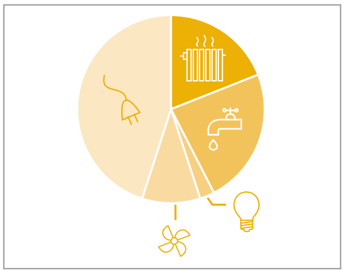
INITIAL OVERHEATING ANALYSIS (GHA TOOL & GUIDANCE)

CORE BPE TECHNIQUE	
Applicable performance objective and target	To not overheat. **Target:** GHA overheating tool score.
Why do it i.e. where it adds value, what it can help with	Overheating in homes has become a significant issue, affecting the comfort and wellbeing of many thousands of people. In the worst cases overheating extends throughout large parts of the year, not just in the warmest months, and the frequency and extent of this are expected to increase with climate change. Use the GHA overheating in new homes tool to assess level of overheating risk. Base the assessment on the scheme as a whole, but take note of any individual units likely to score higher, and consider specific mitigations.
When to do it	At an early design stage, and absolutely before planning. It is wise to review the assessment at key points to check that any design changes won't have unintended consequences impacting on the overheating risk.
How to do it Tips and tricks	The tool includes a one page reckoner that asks 14 questions split between risk factors and mitigations. Each question is scored based on the scheme assessed, with the total score summed at the bottom. An overheating risk assessment cannot guarantee that a home will never overheat during a heat wave or a very swinging party but it is important that any home can cool effectively once a heat event passes, and this is usually achieved via opening windows. Where there are barriers to windows opening the situation becomes more challenging and other options may need to be considered. Mechanical cooling will increase energy consumption, can be costly to run, and the heat rejection can increase temperatures in the local microclimate exacerbating the problem for neighbours. For these reasons mechanical cooling solutions are not recommended if they can possibly be avoided.
Needs an expert?	No.
Cost and time	£
Regulations	Building Regulations do not currently include an effective overheating check (SAP criterion 3 is not considered very robust). It is anticipated that some form of new overheating check may be consulted on soon. The use of the GHA assessment tool is now required by the Greater London Authority (GLA) for referable developments in London.
Specific considerations for timber construction	No significant implications for timber construction. Timber construction dwellings are typically of lighter thermal mass, and lightweight dwellings are more likely to heat up quicker, but equally will cool down faster when well ventilated with cooler air.
What to do with the results? i.e. how to interpret results & identify next steps	If the tool predicts a significant overheating risk (a total score >10) then review elements triggering the higher risk and whether design can be adapted to mitigate some of this risk. **Possible detailed BPE as next step:** If the score cannot easily be reduced then commission a CIBSE TM59 assessment to further explore the risks and suitable mitigation measures.

ENERGY STRATEGY REVIEW



CORE BPE TECHNIQUE.

Applicable performance objective and target	To minimise energy consumption, to keep warm in winter **Targets:** Energy consumption (kWh/m²), space heating demand (kWh/m²), Heat transfer coefficient (W/K), thermal bridges (W/m²K), contribution from on-site renewables (kWh/m²).
Why do it i.e. where it adds value, what it can help with	It is necessary to have some understanding of the energy performance of homes being designed, to be able to meet minimum standards and strive for enhanced performance. Energy performance will be affected by the building form, building fabric, services and equipment. Best results are achieved when all factors are optimised. As a very minimum, all projects should include SAP calculations and a review of the design from an energy perspective. For more onerous targets anddesign input, detailed calculations are recommended – see > ***detailed energy modelling.***
When to do it	At the design stage. Calculations usually need to be revisited several times to ensure that targets continue to be met as the design evolves. Very early stage calculations might only cover one or two sample units, with more units included as the design settles. Calculations must be updated to reflect 'as-built' at completion.
How to do it Tips and tricks	At the design stage, a review of the energy strategy should include: • Passive design principles including orientation, building form and layout, glazing location, glazing areas, and shading • Ventilation: if mechanical (recommended in airtight homes), optimise heat recovery % within MVHR units • Check the duct types and routes; are bends and length minimised? • Heating and hot water: plant efficiency, at full and part load? • SAP calculations: high-level review of results, inputs, consistency with design documentation; is SAP sufficient for the objectives, or are more detailed calculations required – see > ***detailed BPE Energy Modelling*** • Thermal bridging review – see > ***core BPE*** • Designing for airtightness – see > ***core BPE design review*** Focus on predicted energy consumption rather than carbon emissions as these fluctuate depending on carbon factors used.
Needs an expert?	Yes and no: an accredited SAP assessor is required for Building Regulations at completion; at the earlier stages, experienced modellers can carry out the calculations and review, and add value to the design.
Cost and time	£
Regulations	SAP calculations are required to produce an Energy Performance Certificate (EPC) at completion and demonstrate compliance with Part L. The current version (as of August 2020) is SAP 2012. SAP 10.1 has been released and consulted on.
Specific considerations for timber construction	None.
What to do with the results? i.e. how to interpret results & identify next steps	Compare energy calculation results with targets and review possible improvements. Calculations can factor in the contribution from any onsite renewables, but results should also be presented without to represent the performance of the building itself. **Possible detailed BPE as next step:** PHPP, dynamic modelling – see > ***Detailed BPE energy modelling***

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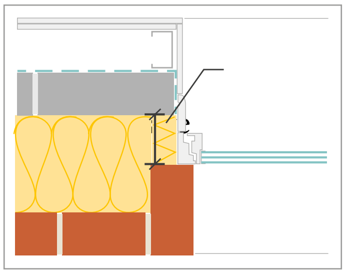
THERMAL BRIDGING AND MOISTURE REVIEW & SITE CHECKS



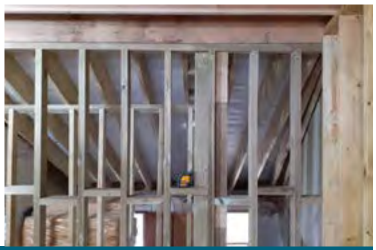
CORE BPE TECHNIQUE.

Applicable performance objective and target	Low energy use; prevent fabric degradation and mould growth **Targets:** Y-value for overall thermal bridging (W/m²K), Ψ value for individual thermal bridges (W/mK).
Why do it i.e. where it adds value, what it can help with	Understanding thermal (or cold) bridging is an important aspect of fabric performance, and it will feed into energy calculations. Thermal ridges are not just a location of heat loss, but can also lead to condensation and mould growth. The design stage review should also check the strategy for moisture content and movement, and assess how details will be built: more complex details introduce greater risks of heat loss and of buildability, so they should be justified.
When to do it	At design stage to inform the proposals and energy calculations. Inspections and spot checks during construction.
How to do it Tips and tricks	**Design stage:** review whether the proposals introduce a risk of high thermal bridging e.g. very articulated facades, discontinuity of insulation at junctions and penetrations, complex details. If so, simplifications should be considered. Establish whether details from Accredited Construction Details (ACDs) or reliable sources can be used, otherwise bespoke calculations will be required – see > ***detailed BPE - Thermal bridge analysis*** and > ***Detailed BPE - Moisture dynamic analysis*** Key principles to check related to moisture include: • Have inwards and outwards moisture flows been considered in the design e.g. selection of materials, air gaps, rain screens etc? Is the approach consistent with the approach to heat flows i.e. vapour control, or breathable approach? • Are the specifications clear on moisture content, and the need to check it at arrival on site and before installation? **Construction:** Inspect how materials are stored and protected from water damage, and spot check the moisture content of timber being installed; spot checks the installation, particularly complex details and possibly with a thermal imaging camera; spot checks the build-up is as per specified, particularly the elements responsible for air, heat and moisture flows (e.g. air gaps, insulation, breathable membranes etc).
Needs an expert?	Could be architect, energy modeller, or Passivhaus designer, but with a good understanding of building physics and materials properties, and experienced in thermal bridging analysis.
Cost and time	£ (review) £-££ (if bespoke thermal bridging calculations required).
Regulations	Building Regulations Part L1A calculations (SAP) take account of thermal bridges; for non-repeating bridges, this can be based on calculations, or a set value if ACDs are used (tbc with future versions of SAP), or a (worse) default value.
Specific considerations for timber construction	Reducing the risk of condensation (surface or interstitial) is particularly important in timber construction, as it could lead to fabric degradation and even structural failure. Risks are often with the structure, so early input from the timber frame manufacturer is recommended.
What to do with the results? i.e. how to interpret results & identify next steps	Note what the key thermal bridges are and whether there are sequencing or other issues that need to be communicated to the site team to ensure they are constructed correctly. **Possible detailed BPE alongside or as next step:** If concerns cannot be resolved, detailed thermal bridge analysis and/or heat & moisture analysis (e.g. WUFI) may be required – see > ***detailed BPE - Thermal bridge analysis*** and > ***Detailed BPE - Moisture dynamic analysis***

SITE VISIT - IN CONSTRUCTION

CORE BPE TECHNIQUE	
Applicable performance objective and target	All.
Why do it i.e. where it adds value, what it can help with	Site visits are an invaluable way to gather information on all aspects of building performance. They should aim to capture general observations as well as key aspects of the fabric and services installation.
When to do it	At several points in the build programme, ideally agreed with the project team early and considering key elements such as airtightness and thermal lines, and ventilation systems.
How to do it Tips and tricks	**Note** - The intention is spot checks with a BPE focus, not a thorough review of the installation such as that from Clerks of Works, which would require a more expansive and defined scope. The BPE visits will show site teams that attention is paid to building performance, and will give an overall indication of whether the project has good procedures and generally seems to implement the agreed design strategy. ☐ Make a note of site procedures, site information etc – site tidiness can be a useful indicator of how a project is run and overall attention to quality. ☐ Are the team aware of performance objectives? Do they seem to have received suitable induction, and training and supervision on key issues such as airtightness? ☐ Are site workers encouraged to report issues such as poorinstallation (e.g. no blame culture)? This can be extremely useful to spot errors when they can still be rectified. ☐ Spot checks that key elements of the building performance strategy are incorporated - see prompts below.
Needs an expert?	Not necessarily, but someone experienced in BPE and construction.
Cost and time	£
Regulations	No
Specific considerations for timber construction	Airtightness and moisture – see specific considerations above.
What to do with the results? i.e. how to interpret results & identify next steps	Site visits and spot checks are inevitably limited and may not be representative, so should not be over-interpreted. They can however be useful pointers for further investigation, and to correlate with other findings e.g. from a review of design changes. **Possible detailed BPE as next step:** More thorough inspections and a review of design changes, if the visits indicate a pattern of poor implementation. A broader review of site procedures and quality management may be needed, as this may raise concerns about overall quality, not only building performance.

SITE VISIT - IN CONSTRUCTION



PROMPTS FOR ISSUES TO LOOK AT

Note – this is not meant as guidance on best practice site procedures, but to highlight key issues that the team should be aware of during their BPE site inspections, as they will facilitate future BPE and help reduce the risk of uncovering performance issues in the later stages of BPE. Additional issues will be identified on each project, for example through past BPE lessons.

Airtightness	☐ See > ***Technique one-pager - airtightness***
Thermal bridging & Moisture (particularly in the case of timber construction)	☐ See > ***Technique one-pager – Thermal bridging and moisture***
Indoor air quality	☐ Check indoor materials are installed as per specifications, including low-emission products. Pay particular attention to materials known to often be an issue, such as glues, varnishes, and processed timber products. ☐ Check air inlets are protected from dust ingress during construction; alternatively, ducts will need cleaning on completion ☐ Checking air inlets are free from blockages (towards the end of construction) ☐ See also moisture, above, as poor moisture management could create mould and air quality issues later on ☐ Commissioning of ventilation: see Core BPE > ***commissioning***
Other examples of spot checks and elements usually needing attention	☐ Windows as designed for good air flow, security and safety etc. ☐ Glazing specifications, openings, shading devices (fixed or movable) as per daylight and overheating strategy ☐ Installation of MVHR e.g. type, routing and fixing of ducts as specified, filters if specified ☐ Water strategy – spot checks on water fittings ☐ Any item identified during the design stage as needing care during construction and installation e.g. complex details, complex systems and their controls

SITE VISIT – IN USE

CORE BPE TECHNIQUE.

Applicable performance objective and target	All
Why do it i.e. where it adds value, what it can help with	A site visit is an invaluable way to gather information on all aspects of building performance. Even a simple walk-around can bring valuable insights, particularly for experienced BPE practitioners.
When to do it	After the first year of occupation, ideally twice in order to capture winter and summer observations. As much as possible this should be when residents are present, for a walk-around with them and to distribute or collect the formal user surveys.
How to do it Tips and tricks	☐ Before any visit, ensure agreements are in place with inhabitants and other users, taking account privacy and ethics. Residents must have explained to them what the site visit will entail, and give permission for any photo and measurement. ☐ It is usually better for at least 2 members of the BPE team to visit together. Surveys should be distributed to all, but not all homes need to be visited – one or a sample is sufficient. ☐ A prompt sheet is provided below with typical issues to look for. In addition, the design review can help identify additional elements that will need checking on site. Furthermore, the visit should be informed by feedback from residents, who may highlight particular issues. Ideally they should be encouraged to show what works and not, room by room. ☐ Note observations on outside conditions during the site visit, and the date and time period (to check local weather and air quality data afterwards).
Needs an expert?	Not necessarily, but someone with experience in both technical and user engagement aspects of BPE.
Cost and time	£
Regulations	No.
Specific considerations for timber construction	n/a, but note any related observations or feedback from users.
What to do with the results? i.e. how to interpret results & identify next steps	Spot checks are inevitably limited and may not be representative, so caution will be needed not to over-interpret them – see advice in "**making sense of it all**". They can however be useful as a pointer for things to investigate further, and to correlate practical observations with user feedback and other BPE results. The site visit may recommend more thorough inspections if the spot checks seem to uncover a pattern of poor implementation. **Possible detailed BPE as next step:** tbc with overall BPE results.

SITE VISIT – IN USE

PROMPT SHEET FOR ISSUES TO LOOK AT

Note – this is not meant as an exhaustive list of issues to look at during site visit, but to highlight typical things to look for during their BPE site visits, as, to cover the main aspects of building performance (people, energy, water, IEQ and fabric) and point to things which often do not work well. Other relevant issues will be identified on a case-by-case basis on each project, including items uncovered through the design and handover reviews, from past BPE lessons, through feedback from inhabitants and other users, and by the very nature of the site visit.

User feedback (residents, but also facilities managers, building mangers, and other regular users e.g. carers in elderly homes, cleaning staff in common areas etc.)

- [ ] Feedback could be gathered very informally, to capture what users want to raise, particularly if more formal user surveys will be carried out and ensure that issues are explored more systematically– see Core BPE > **User surveys**. Even when informal, this can be a highly valuable way to gather feedback, spot issues which could be missed or dismissed otherwise, and put other BPE results into context.
- [ ] Site observations can be general or specific about how it is to live here and (e.g. for building management teams) work in, operate and maintain the building. This could include ease of use, comfort (summer, winter), light and noise levels, perceived air quality, usability and functionality of the home (e.g. storage, cycle storage, access to and quality of outside space…)
- [ ] Are the residents and building management team aware of performance objectives? This is particularly relevant if the project had high aspirations such as low-energy or low-carbon homes, exemplar timber construction
- [ ] User feedback on the design construction and handover process: how involved do they think they could be before, during and after handover e.g. opportunities to learn about and comment on the design proposals, visit the site and comment on handover documentation? Do they know of their building user guide (if there is one), and is it useful and easy to understand? Is the information relevant? What do they think of the support they received in the early period of occupation?

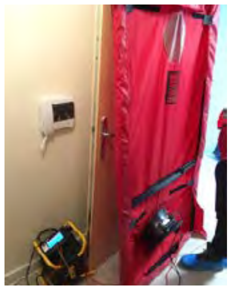
Spot checks on build quality and IEQ

- [ ] Simple visual and hand checks around windows and junctions (on very poor installations on winter days, it is possible to feel the cold air and even, sometimes, to spot gaps)
- [ ] Thermography "spot checks" – see **Detailed BPE > "spot checks"** section; On cold days (and ideally very cloudy days, or early morning / early evening), using thermal imaging to identify cold spots – these could indicate either thermal bridging or air leakage (particularly useful during a depressurisation test, but can still be useful anyway); this could be done informally, outside of a full specialist thermography survey
- [ ] Spot checks on temperature and moisture, using the BPE team's own sensors or taking reading of installed sensors, if present - see **> IEQ "spot checks"** section
- [ ] Signs of mould growth or condensation?
- [ ] Signs of poor air quality e.g. stuffiness, high-VOC smells?
- [ ] General impressions on daylight and views: Do the rooms seem well daylit? Do most have views to the outside, ideally of nature or a pleasant setting such as an active street, rather than, say a car park or busy road?
- [ ] Any observations on temperature, and how this relates to outdoor conditions and the heating set-points?

Spot checks on how well things seem to work

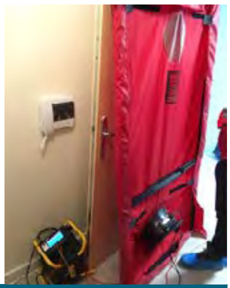
- [ ] Do residents know where their meters are? Are they easy to access?
- [ ] Are all the sensors planned in the design stage (if any) installed, and do they seem to give reasonable readings?
- [ ] **Windows:** do they seem installed as per design including consideration of air flow, security, openings and safety? Are they easy to operate? If the design included restrictors, are they in place, and do they match the design (e.g. they are often installed incorrectly and overly limit opening; inversely, inhabitants sometimes unlock / de-activate them to be able to open windows more widely, for example if they are not satisfied with "stuffiness" or excessive indoor temperatures). Blinds consistently down over glazed areas, particularly full height, could indicate residents feeling too exposed and needing to protect their privacy.
- [ ] **Ventilation:** Do fans seem to work when planned (e.g. intermittent fans on a light switch or presence detection or humidity sensor, depending on the design strategy)? How noisy do they seem to be? Try a few settings, if possible. If there is an MVHR, does it seem easy to use, including different settings? Is it easy to access? Is it easy for residents or maintenance teams to know when to change the filter, and easy to do it? Do residents know they need to do this?
- [ ] **Controls:** How instinctive and useful do they seem to be (e.g. lighting, temperature, ventilation)?
- [ ] **Water strategy:** any feedback from users on the quality of the appliances and fittings? Have they changed (or wish to change) any of them? Note any feedback from users on these elements (if they are present)
- [ ] Note whether changes seem to have been implemented by the users since completion. This could be changes directly aimed at improving usability and comfort (e.g. addition or removal of blinds or other devices for shading and/or glare protection; switching off the ventilation); or changes for other reasons, which could indirectly have an impact on building performance (e.g. furniture stored against glazed areas, impacting light penetration). These issues would be particularly interesting to discuss with users, if they are present, in order to understand why they happened.

AIRTIGHTNESS REVIEW AND TESTING



CORE BPE TECHNIQUE	
Applicable performance objective and target	To keep warm in winter and to minimise energy consumption **Target:** Airtightness – see > ***Client sheet***
Why do it i.e. where it adds value, what it can help with	Good airtightness helps to reduce heat loss, improve comfort by limiting draughts, and reduce the risk of condensation and fabric degradation. It is also useful as general indication of build quality. Checks during the design and construction stages will improve the likelihood of good airtightness being achieved and reduce the need for leak searching and remediation
When to do it	In addition to airtightness tests at completion, checks are recommended throughout: at design stages, during construction, and re-testing in use.
How to do it Tips and tricks	☐ Consider appointing an airtightness champion in charge of management, education and training on site, especially if targets are onerous e.g. Passivhaus. ☐ **Checks at design stage:** see below prompts. ☐ **Checks and inspections during construction:** see below prompts. ☐ First test when the envelope is complete but the airtightness layer still visible, without finishes and services. ☐ Follow-up test once all service penetrations in the fabric have been made and taped. ☐ Final test for PC. At the time of writing, blower door tests are the only ones accepted for Building Regulations purposes. However, low-pressure pulse tests may soon become accepted too. They are less disruptive and offer opportunities for more regular testing during construction and in occupancy. On the other hand, blower door tests offer more opportunities to spot leaks at the same time (e.g. using smoke), while the building is pressurised or during depressurisation.
Needs an expert?	Yes for the final blower door test at PC, but informal tests and checks are possible and recommended throughout construction
Cost and time	££ - formal blower door test, which involves a specialist. Likely to reduce in the future with the spread of low-pressure pulse tests. £ - checks and oversight in design and in construction, possibly additional appointments; will reduce as teams gain experience
Regulations	Yes – blower door test at PC. Low-pressure pulse tests may also become an accepted method in the near future.
Specific considerations for timber construction	Timber dries with heating in use, which may affect airtightness. Good details and installation can address this and allow for movement, but retesting is recommended after a year in use - see > ***moisture management***
What to do with the results? i.e. how to interpret results & identify next steps	Compare airtightness with target and benchmarks. There are several methods to find leaks e.g. smoke during blower door tests; local smoke pen; simply using fingers to feel cold air (easier during pressurisation); thermal imaging to spot colder surfaces indicating air leakage. Leaks should be looked for at all junctions and penetrations e.g. doors, windows, services penetrations, floor-to-wall etc. Wherever possible, apply remediation; options vary with the type of leak and stage of construction, from simple additional tape through to re-installing some elements. **Possible detailed BPE as next step:** n/a

AIRTIGHTNESS REVIEW AND TESTING



PROMPTS FOR QUESTIONS AND ISSUES TO LOOK AT – DESIGN STAGE

Note – this is not meant as detailed guidance for airtight design, but to highlight key principles that the BPE and design teams should be aware of and raise at BPE design reviews. They will facilitate future BPE and help reduce the risk of uncovering performance issues in later stages. Additional issues will be identified on each project, for example through past BPE lessons.

Promts for questions and issues to look at - Design Stage

- [ ] Is the airtightness target specified? Is it in line with initial objectives (see > ***client sheet***)?
- [ ] How simple is the design: articulated facades and complex designs will increase the risk of air leaks and require more complex details, more attention on site, and probably more timeconsuming airtightness testing, leak finding, and remediation.
- [ ] As the design progresses, the aim should be to produce clear drawings for junctions, which can easily be visualised to explain how they will be built. Make a note of risky elements, which will need attention on site.
- [ ] Has there been a buildability and sequencing review, with someone experienced in achieving best practice airtightness?
- [ ] Are airtightness details and sequencing included in the drawings and specifications? Is the airtightness line clear on drawings? If inside the thermal line, this will help with performance and facilitate checks on site.
- [ ] Are the specified materials robust to reduce deterioration over time?

PROMPTS FOR QUESTIONS AND ISSUES TO LOOK AT – CONSTRUCTION STAGE

Note – this is not meant as detailed guidance on site procedures for airtightness, but to highlight key issues that the BPE and design teams should be aware of and raise at BPE design reviews. They will facilitate future BPE and help reduce the risk of uncovering performance issues in later stages. More detailed inspections the appointment of an airtightness specialist would be required for exemplar airtightness, for example if the home targets Passivhaus - see guidance for references on this. Additional issues will be identified on each project, for example through past BPE lessons.

Promts for questions and issues to look at - Construction Stage

- [ ] Do the works follow the sequencing strategy agreed before start on site to achieve the targeted airtightness?
- [ ] Are materials and the installation in line with the airtightness strategy, including the build-up of junctions, the actual selection of as-build airtightness materials (i.e. seals, tapes, etc) and how they are stored and installed. Pay particular attention to the details identified during the design review as particularly complex or risky and to areas which will be difficult to access and improve later e.g. floor-to-wall junctions.
- [ ] The BPE team as well as the site team should carry out inspections and spot checks throughout construction. Areas prone to leaks include all junctions and penetrations, especially complex details.
- [ ] Local testing can also be carried out e.g. first installed windows, mock-ups.
- [ ] Thermography spot checks can potentially be used to help spot sources of air leakage, by highlighting cold surfaces due to cold air (a full survey is not part of the core BPE).
- [ ] **Timber construction:** What are the processes for checking airtightness qualities of timber products are they get delivered on site, and before installation? How are materials stored to limit wetting? See also > **moisture management.**
- [ ] **Timber construction:** Has movement of timber due to wetting / shrinkage cycles been allowed in the installation? e.g. tape between sections of timber, including air tight OSB or SIPs panels, should take account of the likelihood of movement and hence not be applied fully taut; e.g. around openings, using “rabbit-ears”, taping in the corners of openings to minimise the failure of airtightness tapes due to shrinkage of timber elements; on Passivhaus projects, decorators caulk should not be used and silicone mastics should not be part of the airtightness layer.

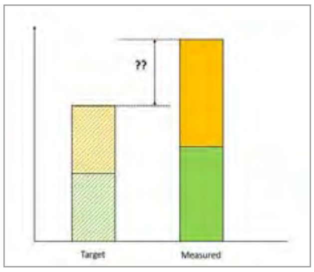
COMMISSIONING

CORE BPE TECHNIQUE	
Applicable performance objective and target	Well performing homes. Energy use, water use, comfort, air quality, noise.
Why do it i.e. where it adds value, what it can help with	Commissioning is an essential activity for enabling systems to operate efficiently and as intended. It is required by regulations but often not done effectively, which can cause many problems e.g. noisy ventilation, insufficient air flow; unreliable metered data. Ideally at each RIBA stage, before sign-off, to embed building performance. Reviews evolve as the project progresses, starting with strategic issues such as elevations, site and building layout, and moving to details and change management in later stages. In-use: to contribute to the overall evaluation of performance.
When to do it	In construction, at post completion, and in use; it needs design consideration to achieve good performance and facilitate BPE.
How to do it Tips and tricks	Commissioning and performance testing must include all systems i.e. heating, cooling (if any), ventilation, lighting, and their controls, as well as metering, monitoring and logging equipment. **Design:** The engineer should specify the performance criteria which systems will be tested against. For ventilation systems, this must include the delivered air flow in each room, operating noise levels, and system balancing. They need to consider how commissioning will be carried out, in particular how the air flow rate will be measured. Time must be allowed in the programme of works. **Construction:** Commissioning happens towards the end of the works, often with pressures on the programme, but the required time must be protected to do it properly. Acoustic testing of the ventilation system (see xx) should be carried out at the same time. On large schemes early homes can be tested and lessons incorporated into the installation of the phases, but all homes should still be commissioned. **PC & handover:** The team should check it has been carried out to the required standards, performance criteria are met, and results are recorded. In the first year there should ideally be seasonal commissioning to check systems work well in different conditions. A check should also be carried out that data from meters, sensors and monitoring equipment seems reliable, to prepare in-use BPE. **In-use:** Records should be reviewed and new tests carried out to check performance and adjust systems if required.
Needs an expert?	Yes – commissioning engineer.
Cost and time	£-££
Regulations	Yes – at completion; no requirement for seasonal commissioning.
Specific considerations for timber construction	No
What to do with the results? i.e. how to interpret results & identify next steps	The systems must be modified until performance criteria are met. **Possible detailed BPE as next step:** some issues may require further investigation to identify remediation options; in severe cases this may even need new installations.

ACOUSTIC REVIEW, CHECKS AND TESTS

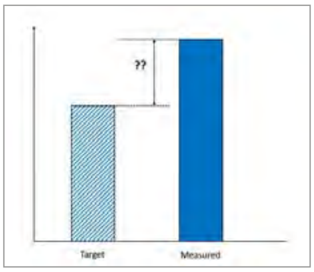
CORE BPE TECHNIQUE	
Applicable performance objective and target	To be quiet and undisturbed inside Targets: regulations + noise from HVAC + others if appropriate
Why do it i.e. where it adds value, what it can help with	Noise levels and disruptions are very important for comfort and satisfaction, and attract some of the highest number of complaints in new homes. Occupants require sufficient levels of sound insulation and appropriate control of noise levels from external and internal (HVAC) sources. Noise from ventilation systems is not controlled under current regulations; it can disrupt sleep and cause inhabitants to turn them off if they are too loud. External noise can limit window opening and increase overheating risk.
When to do it	Review of site noise conditions, acoustic design approach and sound insulation details at the design stage; inspections and tests in construction and at completion.
How to do it Tips and tricks	Acoustic design targets alone are not sufficient – committing to testing helps make sure that appropriate attention is paid to the design, detailing, construction / installation and commissioning of buildings and services. **Design:** The design evolves from the performance targets – whether for site specific aspects such as external noise, or internal details such as sound insulation and design of services. Be aware of external noise sources on site and reflect this in the design e.g. by locating bedrooms on quieter elevations. Ensure the summer ventilation strategy takes account of external noise, with a noise survey if required - see > ***core BPE - early overheating analysis.*** **Construction and PC:** Inspect installation against design and specifications e.g. sealing around partitions; brackets, linings and allowances around water pipes and WCs; fixing of floor decking to avoid creaky floors. Use Robust Details for party walls and floors, or test sound insulation pre-completion (as per Building regulations Part E). Test noise from ventilation systems against targets, as part of the commissioning process.
Needs an expert?	Yes for all the BPE elements: design advice, inspections and testing
Cost and time	££
Regulations	**Building Regulations:** sound insulation between dwellings (E1 - Robust Details or completion testing) and within homes (E2- product testing). **Planning:** to control external noise ingress. Specific considerations for timber construction Building Regulations were developed around
Specific considerations for timber construction	Building Regulations were developed around heavy, masonry constructions; some timber frame details provide high levels of sound insulation, while others can comply with regulations but leave occupants dissatisfied. Twin stud walls usually generally perform well in acoustic terms. Floors in timber framed homes need more attention as there is a propensity towards footstep transmission to rooms below.
What to do with the results? i.e. how to interpret results & identify next steps	People differ widely in their tolerance to noise. Acoustic consultants can help interpret user feedback and other BPE results, relate them to targets and good practice, and advise on mitigation and next BPE steps. **Possible detailed BPE as next step:** depending on issues uncovered e.g. testing of indoor and outdoor noise levels; detailed noise survey of inhabitants; detailed review of as-built drawings and installation; testing for low frequency noise (not considered in Building Regulations).

ENERGY USE AUDIT



CORE BPE TECHNIQUE	
Applicable performance objective and target	Low energy consumption **Target:** Energy consumption (kWh/m²/yr)+ Possible additional targets e.g. space heating demand, energy generation from renewables
Why do it i.e. where it adds value, what it can help with	Energy consumption is an essential metric for understanding overall building performance, running costs and carbon emissions. Homes often consume more than expected, which can only be uncovered and improved with more routine monitoring and analysis.
When to do it	In use, covering at least one year of occupation. Ideally excluding the first year, when inhabitants are "settling in" and systems may be getting fine-tuned: use that year to set things up for data collection, permissions and engagement from inhabitants – see > ***Privacy & Ethics***
How to do it Tips and tricks	As a minimum, an energy audit should use annual readings for the main meters of each energy supply (e.g. from bills, provided they are based on actual rather than estimated readings. Benchmarking should help evaluate performance. As a minimum total annual energy use per m² and per dwelling should be captured. If possible with available data, and with reference to targets set, then include: • separate thermal and electrical energy uses • break down thermal uses into space heating and hot water, and estimate space heating demand via estimated plant efficiency • separate any on-site generation, to report on net and total demand • report on building and total with communal heating, if relevant. • review variations: weekday / weekend, day/night, monthly. It is also useful to relate energy use to occupancy (high/low density, at home/out a lot) and heating degree days (warm/cold year).
Needs an expert?	Not necessarily: could be a non-specialist with some BPE experience.
Cost and time	£-££. Do not under-estimate the time and effort to set things up to make sure data is available and correct
Regulations	No
Specific considerations for timber construction	n/a, other than if identified through fabric performance analysis - see co-heating and airtightness and thermal bridge sections
What to do with the results? i.e. how to interpret results & identify next steps	Compare energy use with targets and benchmarks; investigate possible improvements and reasons for under-performance. Be careful not to over-interpret an initial audit: • Energy use can vary widely for identical dwellings, so conclusions are more reliable if related to occupancy, or across larger samples. • Correlate with other BPE results e.g. space heating with air tightness, Indoor Environment Quality (IEQ) spot checks, user feedback or site observations on indoor temperatures; electrical consumption with observations on occupancy and appliances & hot water energy use with water consumption etc – see > ***Making sense of it all***. Improvement measures could cover a wide range. Making sure things are well commissioned and inhabitants know how to operate their home is an essential step before deeper interventions. **Possible detailed BPE as next step:** Energy monitoring and submetering; plant performance analysis; U-value test; detailed energy calculation review and modelling; occupancy patterns analysis.

WATER USE AUDIT



CORE BPE TECHNIQUE

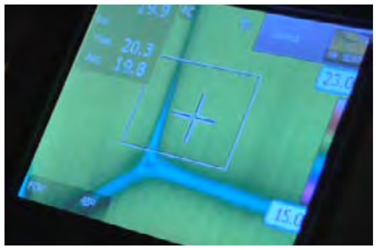
Applicable performance objective and target	Low water consumption. Water consumption target (l/day/person).
Why do it i.e. where it adds value, what it can help with	Water use is an important performance element in itself, and may also relate to energy use. Drought/water shortage is an increasing concern in the UK (less so in Wales).
When to do it	In use, based on min 1 year of occupation and ideally after the first year of occupation.
How to do it Tips and tricks	Use the first year of occupation to set things up for data collection, permissions and engagement from inhabitants – see > ***Privacy and Ethics.*** Design issues affecting water consumption should be considered at the design stage – see > ***design checklist***. Water use should be benchmarked as a minimum in total water use per person per year. If there is on-site water recycling/ re-use displacing mains water, if possible its contribution should be estimated and separated from total demand; similarly, external water uses should be reported separately if possible. Temporary flow meters can be installed for this purpose. The home tour and user surveys can provide indications such as occupancy density, and amount and types of fittings and appliances, which may explain some patterns of water consumption. If possible with the available data, review variations in water use e.g. continuous night-time water use could indicate leaks.
Needs an expert?	Not necessarily: could be a non-specialist, from inside or outside the project team, but with some BPE experience.
Cost and time	£
Regulations	No.
Specific considerations for timber construction	No.
What to do with the results? i.e. how to interpret results & identify next steps	Compare water use with target and benchmarks; investigate possible improvements and likely reasons for under-performance, if relevant. Be careful not to over-interpret, and correlate with other BPE results e.g. occupancy patterns; energy use for hot water; feedback from inhabitants on their fittings and appliances (e.g. they may have replaced poor quality low-flow fittings for higher-flow ones) – see > ***Making sense of it all***. Improvement measures could include fixing leaks, or changing to lower water consumption appliances and fittings. **Possible detailed BPE as next step:** water monitoring and submetering; deep occupancy studies (range of methods)

USER SURVEYS

In winter it's lovely and my heating bills are low, but at first in summer it could get a bit hot in the bedroom. I had to learn how to use the shutters.

CORE BPE TECHNIQUE	
Applicable performance objective and target	Good user comfort and satisfaction.
Why do it i.e. where it adds value, what it can help with	Inhabitant comfort and satisfaction is an essential performance element in itself. It can also help understand other aspects of building performance e.g. energy consumption.
When to do it	In use, based on min 1 year of occupation and ideally after the first year of occupation; ideally with separate summer and winter surveys, to best capture comfort feedback.
How to do it Tips and tricks	Use the first year of occupation to seek permissions and engagement from inhabitants – see > ***Privacy and Ethics*** Surveys are usually a 2-3 page questionnaire asking basic information about the inhabitants and then their perceptions of all aspects of living in their homes. Standardised surveys (e.g. BUS) add value by using considered and well phrased questions and benchmarking results against similar projects. Use survey results alongside feedback from the home tour. Be mindful that people have different comfort requirements, and that perceptions of air quality, humidity and comfort can be very intertwined: consider feedback on these separately, and together, and alongside "hard" measurements Be careful not to over-interpret; correlate with and shed light on all other BPE results e.g. occupancy patterns & energy and water use audits – see > ***Making sense of it all***.
Needs an expert?	Not necessarily: could be a non-specialist, from inside or outside the project team, but with some BPE experience. Using standard surveys (e.g. BUS) is particularly recommended if carried out by non-specialists to ensure robustness and because it compares results against benchmarks, giving context to the findings.
Cost and time	£-££ depending on number of homes and time spent to develop the survey, and on site with residents.
Regulations	No.
Specific considerations for timber construction	No; note any specific feedback e.g. do inhabitants know it is timber construction? Does it have a "feel good factor?" etc.
What to do with the results? i.e. how to interpret results & identify next steps	Compare survey results against targets (if any) and benchmarks; this is facilitated by the use of standard surveys such as BUS Remediation could cover a wide range. Making sure inhabitants know how to operate their home is an essential step before deeper interventions. **Possible detailed BPE as next step:** studies on inhabitants feedback occupancy patterns, and more in depth monitoring of energy, water and plant performance - see > ***detailed occupancy feedback analysis***, ***energy monitoring***, ***water monitoring***, depending on the findings uncovered.

THERMOGRAPHY

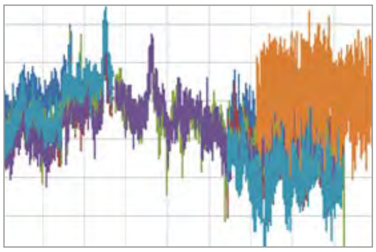


DETAILED BPE TECHNIQUE	
Applicable performance objective and target	Envelope thermal performance and lack of mould growth
Why do it i.e. where it adds value, what it can help with	Thermography can help to locate potential air leakage, mis-applied insulation to fabric and services, thermal bridges and moisture within the building fabric which are not visible to the naked eye. It is nondestructive and non-contact. Thermal imaging results are easy to mis-interpret. A professional survey will provide more robust details and experienced analysis if a detailed inspection and diagnosis are required. However, thermal cameras can be bought or borrowed reasonably cheaply, and used for spot checks as part of a core BPE exercise.
When to do it	During pressure tests in construction or at completion, to help identify areas of air leakage; When homes are occupied, as the tests are nonintrusive and can help spot issues before they become visible and cause serious problems (e.g. condensation, mould growth).
How to do it Tips and tricks	Tests are more useful when performance is poor: surveys may not spot all issues, particularly if very good performance is targeted. Tests are best done in cooler months (there should generally be a temperature difference of at least 10°C between inside and outside) ideally before sunrise, several hours after sunset, or (as a last resort) when very cloudy as direct sun will heat external surfaces and alter results. Focus on areas prone to air leakage or cold bridging such as around windows and doors, at wall/floor/ceiling junctions, on the roof, eaves or within loft space plus around ventilation ducts and drainage pipes. Thermal cameras can also check for continuity of insulation, including in existing buildings. Look at outside of building while the home is pressurised to see where warm air might be leaking out, and inside surfaces while the home is depressurised for cold air leaking in. When surveying services, hot areas indicate poor or discontinued insulation e.g. to pipework or ductwork, or faults to electrical circuits; this is especially useful where services are concealed.
Needs an expert?	Yes for a full survey and detailed analysis; not necessarily for spot checks, but with some experience in order not to mis-interpret results.
Cost and time	£-££
Regulations	None for thermography, but Part C covers continuity of insulation.
Specific considerations for timber construction	None.
What to do with the results? i.e. how to interpret results & identify next steps	Keep a record of the survey with notes on the date, weather that day, where each thermograph was taken and what it may be indicating. **Possible detailed BPE as next step:** U-value calculation; thermal bridging analysis

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

For further information: https://woodknowledge.wales

IEQ MONITORING (AIR, TEMPERATURE, HUMIDITY)



DETAILED BPE TECHNIQUE	
Applicable performance objective and target	Good air quality, mould free, warm in winter, not overheat Project-specific targets e.g. summer temperature, VOC levels
Why do it i.e. where it adds value, what it can help with	IEQ monitoring can apply to a range of parameters important for the health and comfort of inhabitants, and give "hard" data to compare feedback against; it can narrow down issues and remediation options, as inhabitants feedback may be non-specific.
When to do it	In use, ideally after the first year of occupation
How to do it Tips and tricks	Seek permissions and engagement from inhabitants before any monitoring – see > ***Privacy and Ethics***. IEQ monitoring can be expensive and time-consuming, so its scope must be defined by initial BPE e.g. monitor humidity or CO2 if measured air flow rates are acceptable but occupants still complain of "stuffiness"; particulate matter on sites exposed to outdoor pollution (without filters) or indoor fires, particularly if occupants report respiratory issues; temperature over one summer (ideally longer) if feedback indicates serious overheating issues etc. Sensors locations should be agreed with inhabitants and chosen carefully or data will be misleading e.g. avoid direct sun and heat sources. Spot checks and short-term monitoring may be part of a core BPE, with portable and cheaper equipment; results may be less accurate and representative but still add to the other BPE findings.
Needs an expert?	Yes, as results are sensitive to equipment and procedures, and need careful interpretation; in contractual situations or expensive programmes, using accredited labs and equipment is recommended. Simple spot-checks as part of a core BPE could be by a non-specialist, but with some IEQ monitoring experience.
Cost and time	£ for temperature and humidity; £-£££ depending on other IEQ parameters, required accuracy and extent of monitoring. Spotchecks or short-term monitoring in core BPE can be cheaper, but are less accurate and should not be over-interpreted.
Regulations	Could be triggered by radon concerns, by the HHSRS and (in theory but rare) by Approved Document F (RH, NO2, CO, ozone, TVOCs.
Specific considerations for timber construction	Processed wood products, if not specified to be low-VOC, emit formaldehyde. High levels may lead to complaints (e.g. watery eyes, irritation of mouth and noise) and, in the long-term, health issues.
What to do with the results? i.e. how to interpret results & identify next steps	Compare IEQ results against target and benchmarks. Remediationwill depend on the IEQ parameter and the severity of the issue. **If pollutant levels are found above regulatory requirements, the issue must be raised with inhabitants and the client.** **Possible detailed BPE alongside or as next step:** this will depend on IEQ parameters e.g. ventilation performance analysis, detailed comfort survey or occupancy patterns analysis

HEAT TRANSFER COEFFICIENT TEST - CO-HEATING AND OTHERS

DETAILED BPE TECHNIQUE	
Applicable performance objective and target	To keep warm in winter, reduce energy consumption. Target: Heat Transfer Coefficient (HTC)/Heat Loss Coefficient (HLC)
Why do it i.e. where it adds value, what it can help with	Co-heating is an established BPE technique to assess overall fabric heat loss and provide the heat transfer coefficient – HTC (W/K) and heat loss parameter - HLP (W/m2/K). The measured HTC can be related to that predicted by calculations (SAP, PHPP) – see > core BPE - ***energy strategy review***. The test requires 2-3 weeks where the home is empty and heated, and is therefore disruptive and not appropriate routinely. It can be useful following a core BPE exercise where the site visit, documentation review, airtightness test and energy audit indicate high fabric heat loss not explained by poor airtightness. It may also have a role in testing pilot homes before rolling out new housing types. Less disruptive techniques are being developed based on shorter periods or in-use smart meter data. They are not yet at the stage where they could be recommended, but may be soon.
When to do it	Late in construction - the building envelope needs to be complete – and in colder weather.
How to do it Tips and tricks	The test typically needs one week for set up and 2 weeks for testing itself, to obtain results at a range of weather conditions. Essentially, the building is heated electrically to a target temperature, and the test records how much heating is required for temperature to remain stable. It is best carried out in winter as it requires a temperature difference of at least 10°C with the outside. Monitoring of outside conditions (temperature, wind, solar radiation) should happen at the same time; U-value tests and thermography are often carried out alongside to help diagnosis. The heating period will dry out materials, which could affect airtightness; an air pressure test **(core BPE - air tightness testing)** should therefore be done before and after so the average airtightness can be used when interpreting results to calculate the HTC. At the time of writing, co-heating tests are the main accepted method for measuring heat transfer coefficients, and they are a Detailed BPE exercise. However, the BEIS SMETER trials are evaluating options which would, if successful, provide measurements of the HTC in an easier, cheaper and less intrusive way. If this was the case, such tests could usefully be part of a core BPE exercise. Results from the SMETER trials are expected Q2 2021. BPE teams should remain informed of developments, as these innovative tests have much potential for the evaluation of whole building fabric performance.
Needs an expert?	Yes, for the test itself and the analysis.
Cost and time	£££ for co-heating test due to expert involvement, equipment & disruption. Alternative tests, cheaper and less disruptive, may emerge in the future.
Regulations	No.
Specific considerations for timber construction	None other than noting the possible effect on airtightness, which reinforces the need for airtightness testing before and after.
What to do with the results? i.e. how to interpret results & identify next steps	Compare HTC and HLP with design targets or estimates; use alongside other tests (e.g. thermographic survey) to ascertain possible causes and remediation. **Possible detailed BPE as next step:** will depend on findings e.g. U-value testing (often done together); thermal bridge analysis.

PROSIECT CARTREFI O BREN LLEOL
THE HOME-GROWN HOMES PROJECT

ENERGY MODELLING – PHPP & DYNAMIC MODELLING

DETAILED BPE TECHNIQUE	
Applicable performance objective and target	To minimise energy consumption, to keep warm in winter. Energy consumption (kWh/m²), space heating demand (kWh/m²) and other energy uses, contribution from on-site renewables (kWh/m²).
Why do it i.e. where it adds value, what it can help with	Detailed energy modelling includes PHPP, which is used to support the Passivhaus scheme and is considered more robust than SAP. Dynamic thermal modelling can also be used for more detailed analysis. PHPP or dynamic modelling may be triggered to ensure that onerous targets can be met (e.g. Passivhaus), or for a better understanding of likely energy performance, and to inform design decisions.
When to do it	At the design stage and at completion. Energy calculations, especially detailed ones, can be used to inform various design decisions and finetune the design to reduce in-use energy consumption. Calculations usually need to be revisited several times in order to ensure that targets continue to be met as the design evolves.
How to do it Tips and tricks	See > ***core BPE energy review*** tips and tricks, to cover basic principles. Detailed modelling is often used to perform sensitivity analysis on a number of design options e.g. which design strategy or detail performs best for reducing heating energy and reducing overheating risk? Design principles might be tested in detail on a smaller sample of units rather than include an entire scheme. Targeting Passivhaus requires exemplarily low levels of thermal bridging, so PHPP calculations are likely to also require thermal analysis at the same time – see > ***detailed BPE*** Dynamic modelling is more commonly used where new construction techniques or materials are being considered or if there is a specific research angle.
Needs an expert?	Yes: PHPP designer or experienced dynamic modeller.
Cost and time	££-£££
Regulations	SAP calculations are required to produce the EPC
Specific considerations for timber construction	None.
What to do with the results? i.e. how to interpret results & identify next steps	Compare energy calculation results with targets. Review where improvements might be possible. Ensure performance factors are reflected in the design and communicated throughout the build. Consider how energy performance will be validated in use. **Possible detailed BPE alongside or as next step:** thermal bridge analysis; heat and moisture analysis.