Insights from Social Housing Projects

Building Performance Evaluation Meta-Analysis

An Executive Report for

Innovate UK

Prepared by:
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Insights from Social Housing Projects: BPE meta analysis

improving the use of energy in buildings

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CONTENTS

Synopsis 1
1. Background 4
2. Context Setting 7
   General data 7
   Organisational data 8
   Occupancy data 8
   Property and construction data 8
   Building services 10
3. Performance Gap 12
   Fabric testing 12
   Energy system commissioning 17
   Thermo-hygrometric comfort & IAQ 22
4. Process & Culture 24
   Process review 24
   Learnings 27
References 29

Synopsis

In England there were 30,590 new homes added to the social rented sector in 2013/14 which represented 25% of all new homes that year (DCLG, 2014). In contrast to private developers, Registered Providers (RPs) typically demonstrate a greater understanding of the risks associated with failing to deliver upon the designed performance targets of a new dwelling. This is due to the fact that in most cases the RPs are responsible for the resident that occupies the home and also the long term management and maintenance of the property.

It is clear from this study that many RPs are aware of the key role that skills, training and leadership play in bridging the performance gap. However, what is less understood is the business case in terms of best practices and success factors that should underpin a social housing development throughout its whole lifecycle, from the specification of procurement and design, to the implementation of construction, handover, operation and maintenance (O&M).

The Building Performance Evaluation (BPE) programme was an £8m competition funded by Innovate UK (formerly, Technology Strategy Board) to evaluate and assess the post-construction and in-use performance of both domestic and non-domestic buildings. There were 52 new housing projects funded in total, of which 54% (28 projects) were led by RPs.

The National Energy Foundation (NEF) has been commissioned by Innovate UK to undertake an analysis of the data arising from all 28 of the RP led projects. These 28 projects are made up of 83 test dwellings in total. Termed the BPE Social Housing Meta-Analysis, the primary objectives have been to identify the following:

- key success factors (where things worked well and not so well);
- practices which resulted in a significant performance gap;

Abbreviations: BPE, Building Performance Evaluation; BUS, Building User Satisfaction; CHP, Combined Heat and Power; COP, Coefficient of Performance; DHW, Domestic Hot Water; DomEARM, Domestic Energy Assessment and Reporting Methodology; IAQ, Indoor Air Quality; MCS, Microgeneration Certification Scheme; M&E, Mechanical & Electrical; MV, mechanical ventilation; MVHR, mechanical ventilation with heat recovery; NEF, National Energy Foundation; O&M, operation and maintenance; RPs, Registered Providers; SAP, Standard Assessment Procedure; TRV, thermostatic radiator valves; TSB, Technology Strategy Board.
The relative impact of specific attributes such as defects and building services on the performance gap.

The ultimate objective of the study was to inform the wider sector and empower RPs towards taking a lead and becoming champions in combating the performance gap between designed and as-built.

This Executive Report condenses the key findings that emerged from the extensive NEF BPE Meta-Analysis. The headline findings of a series of critical subject areas are outlined below.

Fabric performance

1. The average as-built external wall U-value of 0.220 W m\(^{-2}\)K\(^{-1}\) exceeds the average design U-value of 0.164 W m\(^{-2}\)K\(^{-1}\), with 9 properties (32%) failing to meet Part L1a backstop. Regular on-site inspections are recommended to make sure that the build is being delivered in line with design specifications, in particular with respect to insulation installation.

2. The air tightness of 46% of the BPE test dwellings was below the design intent. All of them performed within the mandatory limits. The average air leakage rate of 4.4 m\(^3\) h\(^{-1}\) m\(^{-2}\) @ 50 Pa outperformed the average design specification of 4.93 m\(^3\) h\(^{-1}\) m\(^{-2}\) @ 50 Pa.

Energy system commissioning

3. Conventional space heating systems such as fossil fuel boilers were associated with a marginal occurrence of issues (0.20 per installation). In contrast, up to 1.60 issues were reported per heat pump system installed.

4. 67% of the plots analysed opted for a mechanical ventilation with heat recovery (MVHR) system as ventilation strategy yet its applicability in social housing is questionable given a number of issues mainly attributable to occupants’ interference, symptomatic of lack of training, and inadequate maintenance regime (1.14 issues per installation). Also, when looked at alongside the mean air leakage rate of 4.4 m\(^3\) h\(^{-1}\) m\(^{-2}\) @ 50 Pa, where 3.0 m\(^3\) h\(^{-1}\) m\(^{-2}\) @ 50 Pa is deemed the threshold for MHVR, the manner in which design and specification decisions are being made appears ineffective.

5. Sub-optimal design and control specifications are at the root of many issues encountered in solar thermal systems, with a notable lack of coordination between contractors and installers reported (0.50 issues per installation). Solar photovoltaic emerges as a more reliable technology, well supported by third party quality assurance schemes (0.17 issues per installation).

Comfort and IAQ monitoring

6. A limited number of test dwellings experienced under heating and hygrometric issues from inadequate relative humidity levels (14 and 12 test dwellings). This is crucial for the RPs’ potentially fuel poor household target.

7. Overheating was more frequent (33 test dwellings), mainly due to occupant window opening behaviour, sub-optimal building design and glazing specifications.

8. Poor indoor air quality (IAQ) levels were generally monitored in mechanically ventilated buildings due to ineffective mechanical ventilation systems or occupants switching off the MV units because of the noise (total issues in 19 test dwellings).

Process and Culture

9. The process review and impact assessment found Soft Landings reported as a useful framework, underpinning successful procurements and best practice.
10. Very few issues were reported by the project evaluators in relation to the Design Phase of any project. This is perhaps partly symptomatic of the conscious environmental design that lies at the heart of the BPE projects but also evidence of a failure to recognise the importance of early design and specification decisions on the long term performance of buildings. Remarkably, only 5 of the 28 projects highlighted that substantial problems occurred across the Construction Phase which had a considerably negative impact on the final product.

11. O&M stands out as the most critical phase where ongoing occupant support is often missing (16 references to bad practice) whilst an accessible induction was generally provided at the Handover Phase (19 references to good practice)

12. All projects converge on the added value associated with BPE studies and although recognising the steep learning curve, many noted the sizable opportunities to transfer the skills gained into future developments.

**Building diagnostics**

13. The overall building performance evaluation methodology prescribed by the BPE programme comes out as a powerful means of bridging the gap between designed and actual energy use that ought to be at the forefront of the political agenda towards meeting the Government CO₂ targets and commitment to ensuring new homes perform as designed.
1. Background

The National Energy Foundation (NEF) has been commissioned to undertake a meta-analysis of the social housing projects carried out as part of the £8m Building Performance Evaluation (BPE) Programme run from 2010 to 2014 by Innovate UK (formerly Technology Strategy Board).

There were 28 BPE projects in total which included the participation of a Housing Association as key actor. Each of these has been extensively reviewed and the associated findings were condensed according to:

- key success factors (where things worked well);
- practices which resulted in a significant performance gap;
- relative impact of specific attributes such as defects and building services on the performance gap.

The study targets a specific user, namely Registered Providers (RPs) (formerly known as Registered Social Landlords). RPs are different from many housing developers in that as owners of new properties they have long term maintenance responsibilities i.e. very clear means, and usually capability, to apply lessons from BPE projects into new developments. An additional benefit is that across the sector RPs have been very receptive to recognise that there is a significant performance gap between new build specifications and real life operation. Many RPs recognise that new in-house and supply chain skills are necessary to deliver energy efficient, and affordable, social housing. What is generally less understood is:

- the relative importance of the cause and effect of performance gaps, as well as the associated costs of mitigation / operation;
- ‘best practice’, or ‘success factors’ at the process (specification, procurement, through to validation tests, handover and operation and maintenance), as well as at a technology level, to bridge the performance gap;
- the economic (business) case for taking action / incurring costs to mitigate the situation.

The 28 BPE projects reviewed as part of the meta-analysis sorted by project ID, study phase, lead organisation and tenure type are listed in Table 1. Phase 1 projects covered the post completion and early occupation phases (6-9 months from handover) whilst Phase 2 projects focused on in-use and post-occupancy typically covering two heating seasons.

The NEF Meta-Analysis consisted of 3 tiers of analysis at an intra-project level providing different levels of information for each project:

- the relative importance of the cause and effect of performance gaps, as well as the associated costs of mitigation / operation;
- ‘best practice’, or ‘success factors’ at the process (specification, procurement, through to validation tests, handover and operation and maintenance), as well as at a technology level, to bridge the performance gap;
- the economic (business) case for taking action / incurring costs to mitigate the situation.

A second phase concerned the aggregation of the findings at an inter-project level to come up with the anonymised findings presented in this Report.

In this regard, it is recognised that the exemplary projects part of the BPE programme outperform the current common practice, a caveat is that they cannot be considered representative of the UK new construction sector, also in the light of the limited sample of projects i.e. the findings are not statistically significant.
Table 1: List of RP / social housing driven BPE projects under review as part of the Meta-Analysis.

<table>
<thead>
<tr>
<th>Project ID</th>
<th>Project name</th>
<th>BPE phase</th>
<th>Lead organisation</th>
<th>Tenure</th>
<th>No of properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>450013</td>
<td>Land at Dormary Court</td>
<td>1-2</td>
<td>Joseph Rowntree Housing Trust</td>
<td>Mixed</td>
<td>4 houses + 2 bungalows</td>
</tr>
<tr>
<td>450018</td>
<td>Lyndhurst Crescent, Swindon</td>
<td>1-2</td>
<td>NPS North East Limited</td>
<td>Social rent</td>
<td>13 houses</td>
</tr>
<tr>
<td>450014</td>
<td>PassivHaus Bungalow Development, Houghton-le-Spring</td>
<td>1-2</td>
<td>Gentoo Group</td>
<td>Rent</td>
<td>28 bungalows</td>
</tr>
<tr>
<td>450016</td>
<td>Building Performance of High Density Apartments</td>
<td>1-2</td>
<td>A2Dominion Homes Limited</td>
<td>Mixed</td>
<td>23 flats</td>
</tr>
<tr>
<td>450019</td>
<td>Future Works social housing Passive House prototypes</td>
<td>1-2</td>
<td>bere:architects</td>
<td>Freehold</td>
<td>2 houses</td>
</tr>
<tr>
<td>450021</td>
<td>Cross Lane Development, Barnsley</td>
<td>1</td>
<td>Sheffield Hallam University</td>
<td>Mixed</td>
<td>18 rental + 4 shared ownership</td>
</tr>
<tr>
<td>450038</td>
<td>Hastoe HA - 14 Passivhaus at Wimbish</td>
<td>2</td>
<td>Hastoe Housing Association</td>
<td>Mixed</td>
<td>6 flats + 8 houses</td>
</tr>
<tr>
<td>450054</td>
<td>Bloom Court</td>
<td>2</td>
<td>Hanover (Scotland) Housing Association</td>
<td>Social lease</td>
<td>6 houses</td>
</tr>
<tr>
<td>450055</td>
<td>The Glasgow House</td>
<td>1</td>
<td>Glasgow Housing Association</td>
<td>None</td>
<td>2 houses</td>
</tr>
<tr>
<td>450056</td>
<td>The Quarries Sheltered Housing</td>
<td>1</td>
<td>Dunedin Canmore Housing Association</td>
<td>Rent</td>
<td>58 flats</td>
</tr>
<tr>
<td>450065</td>
<td>Knights Place Passivhaus Housing for Exeter City Council</td>
<td>2</td>
<td>Gale &amp; Snowden Architects Limited</td>
<td>Rent</td>
<td>18 blocks</td>
</tr>
<tr>
<td>450069</td>
<td>Monitoring of an estate near Rotherham</td>
<td>2</td>
<td>Verco</td>
<td>Social housing</td>
<td>24 houses</td>
</tr>
<tr>
<td>450071</td>
<td>Dungannon Passivhaus</td>
<td>1-2</td>
<td>Choice Housing</td>
<td>Social housing</td>
<td>5 houses</td>
</tr>
<tr>
<td>450073</td>
<td>Scotland's Housing Expo</td>
<td>2</td>
<td>Architecture and Design Scotland</td>
<td>Mixed</td>
<td>52 houses</td>
</tr>
<tr>
<td>450076</td>
<td>Rowan House Passivhaus Social Housing for Exeter City Council</td>
<td>2</td>
<td>Gale &amp; Snowden Architects Limited</td>
<td>Rent</td>
<td>3 flats</td>
</tr>
<tr>
<td>Project ID</td>
<td>Project name</td>
<td>BPE phase</td>
<td>Lead organisation</td>
<td>Tenure</td>
<td>No of properties</td>
</tr>
<tr>
<td>------------</td>
<td>------------------------------------------------------------------------------</td>
<td>-----------</td>
<td>--------------------------------------------------------</td>
<td>--------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>450079</td>
<td>A New Code 4 Approach - High Fabric Insulation with Simple Heating Service</td>
<td>1</td>
<td>South Western Housing Society</td>
<td>Social lease</td>
<td>10 houses + 2 flats</td>
</tr>
<tr>
<td>450081</td>
<td>Tigh-Na-Cladach affordable housing: 1 Passivhaus home &amp; 2 low-energy homes</td>
<td>2</td>
<td>Glasgow School of Arts</td>
<td>Shared ownership</td>
<td>15 houses</td>
</tr>
<tr>
<td>450082</td>
<td>Cross Street, Gainsborough</td>
<td>1-2</td>
<td>Longhurst Group</td>
<td>Social rent</td>
<td>7 houses</td>
</tr>
<tr>
<td>450083</td>
<td>In-use and Post Occupancy Evaluation in Low Carbon Apartments</td>
<td>2</td>
<td>Connect Housing</td>
<td>Social rent</td>
<td>14 flats</td>
</tr>
<tr>
<td>450093</td>
<td>Lea Field Court</td>
<td>1</td>
<td>Joseph Rowntree Housing Trust</td>
<td>Mixed</td>
<td>13 houses</td>
</tr>
<tr>
<td>450096</td>
<td>Thames Valley Houses in Feltham</td>
<td>2</td>
<td>Thames Valley Charitable Housing Association</td>
<td>Social rent</td>
<td>10 houses</td>
</tr>
<tr>
<td>450098</td>
<td>Derwenthorpe</td>
<td>1</td>
<td>Joseph Rowntree Housing Trust</td>
<td>Mixed</td>
<td>540 houses</td>
</tr>
<tr>
<td>450099</td>
<td>Sinclair Meadows Carbon Negative Community Village, Reed Street</td>
<td>2</td>
<td>Four Housing Group (Berwick &amp; North)</td>
<td>Rent</td>
<td>9 houses + 12 flats</td>
</tr>
<tr>
<td>450100</td>
<td>Bryan House scheme, Bicester</td>
<td>1</td>
<td>Sanctuary Housing Association</td>
<td>Rent</td>
<td>7 houses + 16 flats</td>
</tr>
<tr>
<td>450101</td>
<td>Garscube Road Housing - 3 sheltered flats and 3 mainstream flats</td>
<td>2</td>
<td>Queens Cross Housing Association Limited</td>
<td>Rent</td>
<td>117 houses and flats</td>
</tr>
<tr>
<td>450102</td>
<td>Seager Distillery Site Housing Development</td>
<td>2</td>
<td>AECOM</td>
<td>Mixed</td>
<td>38 social rented flats and 92 private flats</td>
</tr>
<tr>
<td>450103</td>
<td>Aberfawr Terrace, Abertridwr, Caerphilly</td>
<td>2</td>
<td>United Welsh Housing Association</td>
<td>Social rent</td>
<td>13 houses + 8 flats</td>
</tr>
<tr>
<td>450104</td>
<td>Barrhead, Murray Place</td>
<td>2</td>
<td>Hanover (Scotland) Housing Association Ltd</td>
<td>Leasehold</td>
<td>16 houses</td>
</tr>
</tbody>
</table>
## 2. Context Setting

### BPE Phases

Of the 28 RP led projects that have been reviewed, 25% (7) belonged to BPE Phase 1 *Post construction and early occupation*; 50% (14) to Phase 2 *In-use performance and post occupancy evaluation*; and 25% (7) undertook both Phase 1 and Phase 2 (Figure on the right).

### Building Procurement Contract

The majority of RP led projects (12) have been procured on a Design and Build basis. In 6 cases the type of building procurement contract was not stated (Figure at the bottom).

### Tenure

Mixed ownership (8 projects) was the most common type of tenure, followed by Standard (7) and Social (5) Rent.
Organisational data

Experienced in sustainable building design
- 8 project teams declared former experience in sustainable building design
- 3 project teams didn’t have previous experience in this field
- Insufficient evidence to make a call in the other 17 projects

Experienced in social housing
- 9 project teams already dealt with social housing
- 1 project team didn’t
- Insufficient evidence to make a call in the other 18 projects

Occupancy data

Occupancy type
- 17 projects of mixed use
- 6 projects for elderly
- 1 project with sheltered occupants

Property and construction data

Focus BPE dwellings
In total, 83 properties undertook the BPE study - each project on average consisted of 2 test dwellings.
- 41 houses
- 29 flats/apartments
- 8 bungalows
- 1 cottage
- 4 unknown property types

Construction Standard
- 26 CSH Level 4
- 15 National Technical Standard
- 12 Passivhaus
- 12 CSH Level 5
- 6 Ecohomes – excellent
- 5 CSH Level 3
- 3 Green Guide to Housing Specification
- 2 CSH Level 6
BPE dwellings characterised in relation to the property type and the construction standard: across each project (above) and in total terms (below).

**Property type vs Construction Standard**

- **Property type:** Cottage, House, Flat/Apartment, Bungalow, Unknown
- **Construction Standard:** Passivhaus, CSH Level 3, CSH Level 4, CSH Level 5, CSH Level 6, Green Guide to Housing Specification, Ecohomes - excellent

**Insights from Social Housing Projects: BPE meta analysis**
Building thermal mass
The thermal inertia of the BPE test dwellings was categorised according to the construction type specified by the BPE evaluators (heavy vs lightweight). In total, 30 projects reported a heavyweight construction; 22 were described as lightweight and 31 did not declare the thermal mass.

Main glazing type
The projects have shown an approximately even spread in terms of glazing types. Triple glazing was the most common being reported in 37 test dwellings, followed by double glazing in 30 dwellings. In 16 cases the type of glazing was not declared.

Primary space heating systems
- The most recurring space heating systems were the traditional fossil fuel fired combi and standard boilers
- Electric heating was a common alternative in particular in Passivhaus certified properties typically reliant upon electrically integrated heat pumps
- Exhaust and air-source heat pumps were the most common types of heat pumps in use (10% and 6%)
- Although still uncommon in the domestic sector, combined heat and power (CHP) was used in 9 of the BPE test dwellings

Space heating controls
- Time and temperature resulted the most common space heating control in place, followed by thermostat and thermostatic radiator valves (TRVs)
- 5% of the BPE test dwellings did not specify the type of control in use
Domestic hot water systems
- Domestic hot water (DHW) was predominantly supplied from the main heating system
- Electric water heating occurred in 13 dwellings
- Fossil fuel standard boilers run in 12 properties

Passive and mechanical ventilation (MV) systems
- The majority of ventilation systems in place consisted of mechanical ventilation with heat recovery (MVHR) (67%)
- Mechanical ventilation with no heat recovery was marginal (5%)
- 24% of the test dwellings had extract only and relied upon natural ventilation

Renewables
- 80% of the properties exploited renewable sources to cover a part of the energy demand
- Solar thermal was exploited in 28 of the properties, solar photovoltaic in 23 properties. Both systems operated in 15 properties

Design U-values
All of the properties have design U-values within the Part L1A limiting fabric parameters.
- Min: 0.088 W m⁻²K⁻¹ (wall); 0.076 W m⁻²K⁻¹ (floor); 0.074 W m⁻²K⁻¹ (roof)
- Max: 0.280 W m⁻²K⁻¹ (wall); 0.250 W m⁻²K⁻¹ (floor); 0.190 W m⁻²K⁻¹ (roof)
- Average: 0.164 W m⁻²K⁻¹ (wall); 0.142 W m⁻²K⁻¹ (floor); 0.122 W m⁻²K⁻¹ (roof)
3. Performance Gap

U-value testing – Introduction

At the core of the performance gap, underperforming building envelopes deviating from the design intent result in higher transmission losses through the building fabrics and contribute to building energy use being higher than originally predicted (ZCH, 2014a; 2014b). This might be due to a number of reasons such as flawed design calculations, quality of materials below what expected or inaccuracies of testing equipment.

The charts below compare the design vs as built thermal transmittances of external walls and roof/ceilings in the dwellings object of U-value testing. The two doughnut-charts at the bottom summarise the respective incidence of the performance gap across the test dwellings in terms of number of properties below and above (0-25% / 25-50% / 50-100% and +100%) the design U-value. The key findings are finally discussed.
Performance gap frequency - wall U-values

- 17% +100% above target
- 8% 50-100% above target
- 15% 25-50% above target
- 27% 0-25% above target
- 33% Below as-design

Performance gap frequency - roof U-values

- 11% Below as-design
- 44% +100% above target
- 22% 0-25% above target
- 11% 25-50% above target
- 11% 50-100% above target

Design vs As Built Roof/Ceiling U-values

- Design U-value
- As built U-value
- Part L1A limit

Insights from Social Housing Projects: BPE meta analysis
U-value testing – Key Findings

Walls
- In 33% of the BPE test dwellings the external walls were performing in line or below the target U-value. This witnesses the value of these exemplary buildings that are pioneering a shift of culture within the UK domestic building stock.
- The overall average as-built U-value of 0.220 W m⁻²K⁻¹ exceeds the average design U-value of 0.164 W m⁻²K⁻¹.
- 9 properties were above PartL1a fabric limit of 0.30 W m⁻²K⁻¹.

Roofs and ceilings
- 1 out of the 9 properties under review was below the design U-value.
- The overall average as built U-value goes beyond the building regulations backstop.
- This is where the major opportunity for improvement lies and stresses the urgency of improved insulation detailing on both warm and cold roofs, in particular with regard to discontinuities in the loft insulation layer often interrupted as an after-thought through service penetrations.

Floors
- 3 properties carried out ground floor U-value testing, with design targets in the region of 0.10 to 0.20 W m⁻²K⁻¹ and actual performance varying from 0.10 to 0.405 W m⁻²K⁻¹.

Recommendations
- Energy conscious design and the implementation of quality control systems on a par with the Passivhaus Certification system as key leverages to bridge the gap between design specifications and in-situ measured values.
- Service penetrations to be concentrated in carefully controlled zones.
- Skilled workmanship.
- Construction databases to better reflect the thermo-physical characteristics of the construction materials on the market and address materials underperforming compared to their specifications.

Air tightness testing – Introduction

Whilst ventilation plays a key role for pollutant dilution and to mitigate condensation phenomena, uncontrolled air infiltration through the building fabric (background ventilation) can give rise to thermal discomforts and excessive ventilation losses increasing the building energy consumption. The Building Regulation Approved Document L1a sets out a binding air leakage rate of 10 m³m⁻²h⁻¹ at a 50 Pa pressure differential. However, mechanically ventilated buildings levering on the ‘build tight-ventilate right’ principle can aim at values as low as 0.50 m³m⁻²h⁻¹ as specified by the Passivhaus standard. The average air infiltration rate in the UK domestic building stock is estimated at approximately 11.5 m³m⁻²h⁻¹ (Stephen, 2000).

The in-situ air tightness tests undertaken in 74 BPE test dwellings have been compared against the design intention using an average when multiple tests were carried out. The results are plotted in the chart below and then aggregated in the doughnut chart. The key findings are finally discussed.
Design vs In Situ Air Tightness

Fabric air permeability (m³·h⁻¹@50 Pa)

- Designed air tightness
- In situ air tightness testing
- Part L1a limit
- Average UK

Insights from Social Housing Projects: BPE meta analysis
**Performance gap frequency - Air Tightness**

- 14% +100% above target
- 18% 50-100% above target
- 12% 25-50% above target
- 11% 0-25% above target
- 46% Below as design

**Air tightness testing – Key Findings**
- Nearly half of the BPE test dwellings reviewed successfully perform to a high standard and as per the design intent.
- BPE test dwellings were very airtight by UK standards. The average in-situ air leakage is as low as 4.4 m³/m²·h @ 50 Pa and below the average design specification of 4.93 m³/m²·h @ 50 Pa.
- Apart from one test possibly biased by a technical fault, all tests perform below backstop Part L1a target and the UK average air permeability.

**Recommendations**
- Maximise air tightness and design a bespoke ventilation build tight-ventilate right strategy.
- Embed an airtightness testing strategy within the construction programme to implement at pre-determined time steps.
- Avoid supplementary controllable ventilators typically placed as an after-thought by the installer as their impact on the thermal performance of the building envelope is frequently poorly understood.
- Be mindful of progressive drops in air tightness levels due to degradation of seals over time.
- Airtightness targets to be well communicated, evaluate training for on-site personnel.
- Co-ordination between building contractors and Mechanical & Electrical (M&E) contractors to prevent unwanted air leakage paths to accommodate service outlets.
- Take into account the impact of how the occupant operates natural ventilation on indoor environmental conditions.
# Energy system commissioning

## Introduction

Commissioning plays a pivotal role in running the building energy systems in conformance with the design intent and prevent problems from deteriorating over time if not promptly addressed. The key issues flagged by the BPE evaluators across a variety of building services & technologies have been analysed to give RPs an understanding of which problems are more likely to occur in relation to specified systems.

<table>
<thead>
<tr>
<th>Building services &amp; renewables</th>
<th>Energy system</th>
<th># test dwellings</th>
<th># key issues reported</th>
<th># key issues per installation</th>
<th>Ranking (+legend)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive/mechanical ventilation</td>
<td>MVHR</td>
<td>56</td>
<td>64</td>
<td>1.14</td>
<td>-</td>
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<tr>
<td></td>
<td>Mechanical</td>
<td>4</td>
<td>3</td>
<td>0.75</td>
<td>□</td>
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<tr>
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<td>Extract</td>
<td>20</td>
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<td>Passive</td>
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<td>1</td>
<td>1.00</td>
<td>□</td>
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<tr>
<td></td>
<td>None (natural)</td>
<td>2</td>
<td>0</td>
<td>0.00</td>
<td>□</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>73</strong></td>
<td></td>
<td><strong>0.88</strong></td>
<td></td>
</tr>
<tr>
<td>Space heating</td>
<td>Fossil fuel boiler (combi)</td>
<td>20</td>
<td>4</td>
<td>0.20</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Exhaust air heat pump</td>
<td>8</td>
<td>9</td>
<td>1.13</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Fossil fuel boiler (standard)</td>
<td>19</td>
<td>8</td>
<td>0.42</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Biomass boiler (combi)</td>
<td>6</td>
<td>6</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Not stated</td>
<td>2</td>
<td>0</td>
<td>0.00</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td>Electric heating</td>
<td>12</td>
<td>0</td>
<td>0.00</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Air source heat pump</td>
<td>5</td>
<td>8</td>
<td>1.60</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ground source heat pump</td>
<td>2</td>
<td>2</td>
<td>1.00</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td>Communal heating CHP</td>
<td>9</td>
<td>6</td>
<td>0.67</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>43</strong></td>
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<td><strong>0.52</strong></td>
<td></td>
</tr>
<tr>
<td>DHW</td>
<td>Fossil fuel boiler (combi)</td>
<td>20</td>
<td>3</td>
<td>0.15</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Exhaust air heat pump</td>
<td>8</td>
<td>3</td>
<td>0.38</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Fossil fuel boiler (standard)</td>
<td>12</td>
<td>3</td>
<td>0.25</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Biomass boiler (combi)</td>
<td>6</td>
<td>0</td>
<td>0.00</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Not stated</td>
<td>8</td>
<td>1</td>
<td>0.13</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Electric water heater/immersion heater</td>
<td>13</td>
<td>3</td>
<td>0.23</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Air source heat pump</td>
<td>4</td>
<td>2</td>
<td>0.50</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Ground source heat pump</td>
<td>2</td>
<td>0</td>
<td>0.00</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Communal heating CHP</td>
<td>9</td>
<td>0</td>
<td>0.00</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Hot water cylinder</td>
<td>1</td>
<td>0</td>
<td>0.00</td>
<td>□</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>15</strong></td>
<td></td>
<td><strong>0.18</strong></td>
<td></td>
</tr>
<tr>
<td>Renewables</td>
<td>Solar photovoltaic</td>
<td>23</td>
<td>4</td>
<td>0.17</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Solar thermal and photovoltaic</td>
<td>15</td>
<td>9</td>
<td>0.60</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Solar thermal</td>
<td>28</td>
<td>14</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>17</td>
<td>0</td>
<td>0.00</td>
<td>□</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>27</strong></td>
<td></td>
<td><strong>0.33</strong></td>
<td></td>
</tr>
</tbody>
</table>

Insights from Social Housing Projects: BPE meta analysis
General Findings

Reported issues have been grouped under the general headings of services design / operation and maintenance / installation / value engineering / commissioning / occupants / handover / controls.

Overall, services design and installation together cover half of the total issues reported, symptomatic of shortage of skills and training within the sector. O&M follows with 30 issues reported, highlighting its importance throughout the building service life and the crucial requirements for ongoing support after handover, often neglected. Problems related to commissioning and controls are less common, those related to occupants, handover and insufficient value engineering marginal.

Building services & renewables

Ventilation
- Small number of issues reported per extract only systems due to the low degree of technical complexity – care when choosing the exhaust outlet location.
- Under-performance of the mechanical extraction units – endemic issue within the UK building stock?
- Insufficient sample of installs to come up with robust findings in relation to mechanical ventilation and ground source heat pumps.
- MVHR does not appear ready for widespread adoption within the social housing sector (see separated focus).

Space heating
- Combi and standard fuel boilers provide simple and well-established systems to supply the building heating energy demand with marginal occurrence of issues – potentially exemplifying the contrast between how the industry copes well with something established and relatively badly with newer technologies stressing the crucial need of training. In respect to heat pumps in particular, the huge diversity of configurations (DECC, 2014) does not help.
- Electric heating is often suitable in properties with a very limited space heating demand (e.g. <15 kWh m\(^{-2}\)) – minimal issues due to ease of use and low maintenance requirements.
- Insufficient sample of installs to come up with robust findings in relation to ground source heat pumps.

Domestic hot water
- Very few issues reported – all systems generally reliable for DHW production. Combi boilers are one of the success stories.

Renewables
- Solar photovoltaic systems have experienced few issues being a well-established technology supported by quality assurance schemes such as the Microgeneration Certification Scheme (MCS).
- Solar thermal tells a different story (see separated focus).
**MVHR – Key findings**

Heat recovery integrated mechanical ventilation is projected to achieve the next steps in energy savings in high energy performance buildings where ventilation heat loss covers a predominant quota of the overall building energy demand (Fabrizio et al., 2014). However, their current applicability in social housing is questionable as evidenced by the frequent occurrence of issues captured by the BPE evaluators. On average, 1.14 issues were reported per MVHR-equipped property. In particular, O&M by vulnerable households was problematic and coupled with system unbalancing often led MVHR to underperform.

### MVHR common issues

<table>
<thead>
<tr>
<th>Common Issue</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unbalanced system supply-extract (human error / faulty equipment)</td>
<td>- Check filters.</td>
</tr>
<tr>
<td></td>
<td>- Re-balance the airflow rates.</td>
</tr>
<tr>
<td></td>
<td>- Test that the manufacturers supplied fans meet the minimum flow rates originally intended.</td>
</tr>
<tr>
<td></td>
<td>- Re-commissioning or replace underperforming fans.</td>
</tr>
<tr>
<td><strong>Blocked filters</strong></td>
<td>- Filter cleaning every six months as a term of contract with the maintenance team.</td>
</tr>
<tr>
<td><strong>Occupants do not know how to operate the system</strong></td>
<td>- Educate occupants and show how the filters can be changed to those interested.</td>
</tr>
<tr>
<td><strong>Occupants’ interference</strong></td>
<td>- Knowledge transfer on optimal window opening, MVHR operation and kitchen extracts.</td>
</tr>
<tr>
<td><strong>Difficulty of access for maintenance</strong></td>
<td>- Evaluate variable speed systems or CO₂ detection sensors.</td>
</tr>
<tr>
<td><strong>Excessive system resistance and noise, leading occupants to turning off the units</strong></td>
<td>- Ongoing technical support.</td>
</tr>
<tr>
<td><strong>Over-pressurisation of the external fabrics</strong></td>
<td>- Knowledge transfer on optimal window opening, MVHR operation and kitchen extracts.</td>
</tr>
</tbody>
</table>

### Recommendations

- Be aware of potential discrepancies in test results attributable to differences in the equipment used to undertake the duct flow measurements, and of the weather conditions that might have affected the results (typically, very windy days)
- Building Regs to steer in relation to flow measurements and commissioning procedures.
- Ensure ease of access to the platform where the unit is installed.
- Improved ductwork connections (flexible-rigid) at ceiling terminals avoiding bends and offsets.
- Verify if the air intake louvres are blocked causing pressure loss and the fans running more intensively to compensate.
- Educate the user to operate the system more efficiently.
- Balance volume flow rate for extract and supply.
- Make sure air transfer paths via door undercuts are not excessively small (e.g. < 5 mm).
Space heating – Key findings

Heat pumps were associated with a number of issues in particular at the installation phase. Frequent problems occurred in heat pumps and biomass boilers in relation to the services design. The design of the controls not being fit for the elderly or users with restricted mobility have been reported across properties running CHP and heat pump systems, although a correlation between the issue and the system in place does not necessarily exist.

Key issues per property - specified space heating energy systems

<table>
<thead>
<tr>
<th>Energy system</th>
<th>Common issues</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>All heat pumps</td>
<td>Low installation standard e.g. unit / fan speed switch inaccessible</td>
<td>Contract MCS accredited installers, on the basis of sufficient post-installation support and maintenance guarantee through service contracts.</td>
</tr>
<tr>
<td></td>
<td>Incorrect temperature readings</td>
<td>Verify that the external temperature sensor isn’t exposed to direct sunlight and compressor and immersion sensors are correctly placed.</td>
</tr>
<tr>
<td></td>
<td>Unbalanced underfloor systems, inadequate flow temperatures, lack of controls/system communication</td>
<td>- Training. - Re-commissioning, collect documentation and commissioning reports.</td>
</tr>
<tr>
<td></td>
<td>Occupants’ interference / disengagement</td>
<td>- Improve owner and user knowledge. - Improve customer care, prompt response and repair services.</td>
</tr>
<tr>
<td></td>
<td>System performance deteriorating over time</td>
<td>Detail maintenance schedule and seasons commissioning.</td>
</tr>
<tr>
<td></td>
<td>Inefficiencies during very cold weather – Coefficient of Performance (COP) is too low</td>
<td>Evaluate the potential mismatch between expected (typically predetermined in the Eurovent Certification) and real operating conditions to ensure that a heat pump averagely operates at an appropriate output.</td>
</tr>
<tr>
<td>Biomass boilers</td>
<td>Underperformance against manufacture’s specs, inefficiencies and distribution losses</td>
<td>- Recognise that SAP indications do not necessarily reflect actual distribution efficiencies. - Insulate ductwork. - Evaluate if the heat demand is sufficient to offset the district heating system inefficiencies.</td>
</tr>
<tr>
<td></td>
<td>Inadequate temperature control zoning</td>
<td>Refer to Domestic Heating Compliance Guide.</td>
</tr>
<tr>
<td></td>
<td>Restricted access to space heating programmers for users with restricted mobility</td>
<td>Allow sufficient headroom for comfortable access to the programmer.</td>
</tr>
<tr>
<td>CHP</td>
<td>Controls not user-friendly</td>
<td>Aim at user-friendly control panels, educate the users and provide ongoing support.</td>
</tr>
<tr>
<td></td>
<td>Distribution losses</td>
<td>Ensure all pipes leading from the unit have been insulated.</td>
</tr>
</tbody>
</table>
Solar thermal – Key findings

A considerable number of the issues emerged from the review of solar thermal systems are associated with sub-optimal design and controls specifications that result in incorrect setup, unforeseen failures and cost uplifts. An optimal control system should be specified as part of the procurement relying upon third party accredited professionals. Particular attention also on roof integrated technologies that trade-off aesthetics with more problematic maintenance needs and costs.

<table>
<thead>
<tr>
<th>Solar thermal common issues</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over simplistic controls settings not tuned to the solar irradiance levels</td>
<td>Contract accredited manufacturers / installers e.g., an M&amp;E contractor with MCS certification could be required as part of the design specification and detailed control units specified in the procurement.</td>
</tr>
<tr>
<td>Immersion heater inefficient operating regime</td>
<td>Re-commissioning.</td>
</tr>
<tr>
<td>Integrated design</td>
<td>Understand the implications throughout the system lifespan in terms of potential failure rates, maintenance requirements and the costs associated.</td>
</tr>
<tr>
<td>Overheating in summer</td>
<td>Continuous solar thermal pipework insulation of adequate specification.</td>
</tr>
<tr>
<td>Controls in inaccessible loft</td>
<td>User access to readings may assist remote faults diagnosis speeding up trouble shooting.</td>
</tr>
<tr>
<td>Poor coordination between installers / main contractor's plumbing and heating contractor</td>
<td>Soft landings.</td>
</tr>
</tbody>
</table>
Introduction

Thermo-hygrometric comfort refers to a status of thermal neutrality experienced by an individual whose mechanisms of behavioural and vasodilation thermoregulation are inactive i.e. a psycho-physic feeling of wellbeing and satisfaction perceived in relation to the surrounding environment. Indoor Air Quality (IAQ) is typically acceptable at CO$_2$ concentration levels below 1000 ppm.

Temperature, humidity and CO$_2$ levels monitored in the BPE test dwellings have been reviewed and categorised in relation to:

- Monitoring data indicating that the building suffers from under heating.
- Monitoring data indicating that the building is slow to warm up (start-up period) and poor temperature control when heating is on.
- Monitoring data identifies overheating as a concern.
- Monitored humidity levels fall outside accepted comfort levels (40-70%, CIBSE) for a significant percentage of the time.
- Monitored CO$_2$ concentration indicative of poor air quality (>1000 ppm, ASHRAE).

Responses to the building user satisfaction (BUS) surveys have been not deemed a representative proxy of comfort due to subjective and psychological biases such as the forgiveness factor linked to previous housing experienced by vulnerable households.

Thermo-hygrometric discomfort and poor IAQ occurrence across the BPE test dwellings
Key findings

Although findings might be undermined by different comfortable metrics used by BPE evaluators to call an under-over heating / poor IAQ scenario, overheating ultimately emerges as the key issue faced by RPs and typically traces back to deficiencies in the building design (sub-optimal orientation and glazing specifications). Crucially for the potentially fuel poor households targeted by RPs, under heating and hygrometric issues are less common. Poor IAQ is reported more frequently, in relation to mechanical ventilation systems not working effectively or insufficient window opening in naturally ventilated buildings, although this might have been affected by the reduced body of evidence.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Common causes</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under heating</td>
<td>Fuel poverty. Uncomfortable ambient air temperatures maintained for a significant percentage of the time within the property to save on bills.</td>
<td>- The problem should not arise if the building was performing as designed.</td>
</tr>
<tr>
<td></td>
<td>Occupant’s preference for low ambient air temperatures / high natural ventilation rates.</td>
<td>Discourage natural ventilation in mechanically ventilated buildings.</td>
</tr>
<tr>
<td></td>
<td>Occupant window opening behaviour.</td>
<td>Awareness raising actions in particular with mechanical ventilation in place.</td>
</tr>
<tr>
<td></td>
<td>Space heating controls difficult to operate.</td>
<td>Knowledge transfer and practical demonstrations.</td>
</tr>
<tr>
<td></td>
<td>Faulty indoor air temperature sensors.</td>
<td>N.a. – the test is biased.</td>
</tr>
<tr>
<td>Overheating</td>
<td>Occuapt window opening behaviour – summer.</td>
<td>- Understand the psychological drivers behind.</td>
</tr>
<tr>
<td></td>
<td>Occupational preference for high ambient air temperatures with secondary heating sources (generally electrical) on outside of the heating period.</td>
<td>- Awareness raising actions in particular with mechanical ventilation in place.</td>
</tr>
<tr>
<td></td>
<td>Heat waves.</td>
<td>- Recalibrate the air change rates via the MVHR system to compete with natural ventilation.</td>
</tr>
<tr>
<td></td>
<td>Building design – orientation, glazing-to-wall ratio, incorrect glazing specifications (g-value), contributing to excessive solar gain.</td>
<td>Awareness raising.</td>
</tr>
<tr>
<td></td>
<td>Failure in the mechanical ventilation system summer bypass.</td>
<td>N.a.</td>
</tr>
<tr>
<td>Hygrometric issues</td>
<td>Too dry – relative humidity dropping below the CIBSE recommended lower limits due to windows regularly opened in winter resulting in additional heating loads or during prolonged unoccupied periods</td>
<td>Best practice and common sense in building design.</td>
</tr>
<tr>
<td></td>
<td>Too wet – condensation and mould formation in wet rooms.</td>
<td>Re-commissioning.</td>
</tr>
<tr>
<td>Poor IAQ</td>
<td>Ineffective mechanical ventilation.</td>
<td>Understand how the occupants interact with windows.</td>
</tr>
<tr>
<td></td>
<td>Occupants switching off MV unit being too loud.</td>
<td>Improve ventilation regime. Verify if the ventilation boost typically actioned via the bathroom light switch is working.</td>
</tr>
<tr>
<td></td>
<td>Occupancy levels higher than expected / sedentary lifestyle of residents.</td>
<td>Regular maintenance of the MVHR filters.</td>
</tr>
<tr>
<td></td>
<td>Leaky duct.</td>
<td>Advise occupants of the purpose of the MVHR system.</td>
</tr>
</tbody>
</table>

Insights from Social Housing Projects: BPE meta analysis
4. Process & Culture

Introduction

Each project’s phase (procurement, design, construction, O&M, handover) has been reviewed in the light of what worked well and what less to come up with a good/bad practice split (radar chart), which was then allocated to a relative impact factor – high, medium or low (square charts). Albeit the findings are strictly built upon the evidence supplied by the BPE evaluators, subjective calls were in some cases necessary.

Key findings

The conscious environmental design at the heart of the projects resulted in the predominance of good practices reported during the Design Phase. Notably, only 5 projects flagged relevant problems in relation to the Construction Phase – which in the majority of cases were considered of good standard despite all the unforeseen events that can arise during the construction process. O&M is where the major problems have been reported and is probably what RPs should prioritise with a view to address the performance gap, with understanding the variables that govern the occupant behaviour standing potentially out as the biggest challenge to face up. The Handover Phase was generally positive in the way occupants are introduced to the building. Overall a high level of correlation between the original design intent and the delivered project has resulted in high quality, low carbon social housing schemes.

Process Rating and Impact Assessment

Insights from Social Housing Projects: BPE meta analysis
## Best Practice throughout Construction Process

### PROCUREMENT
- Minimise deviations from the original scheme design or specification.
- Shared agreement on specific design decisions prior to the appointment of the building contractor.
- Contract design team with a track record in environmental design.
- Collaborative approach and collective experience to tackle the challenges faced up throughout the construction process.
- Evaluate the case for retentions to achieve the design intentions.

### DESIGN
- Sustainable building design approached at early stages, stemming from a holistic approach to the occupants’ quality of life and the environment – sustainability certification systems as a possible integrated steer to sustainable design principles.
- ‘Fabric first’ design approach. Aim at cost optimal levels of energy performance (EPBD recast 2010/31/EU).
- Participatory design.
- Multi-disciplinary design team.

### CONSTRUCTION
- Appoint a clerk of works – regular on-site inspections to check that the build is being delivered in line with design specifications. Particular attention to insulation installation.
- In-situ thermal performance tests, in particular air-tightness.
- Set up a formal change management process to ensure that any deviations from designs are discussed and performance repercussions managed.
- No blame culture.

### HANOVER
- ‘Soft Landings’ handover events and introductory workshops with design and technical team, client, maintenance staff, and tenants, including feedback sessions to engage residents. Advice should be given in a non-technical manner that is accessible to laypeople, in particular in relation to novel technologies.
- Handover of tenant information pack upon arrival at the property including ‘quick start’ guide, complete User Guide and operation manual.

### O&M
- Training for occupants and maintenance team, at the outset and during occupation. Feedback workshop during the first year after handover. User-friendly user guide to provide simple operation details.
- Dedicated Customer Care for 1 year following occupation. Set up a repairs helpline to reporting operational problems to cover defects liability periods.
- Be aware of possible forgiveness factor and residents reluctance to complain.
The key learning points from the projects have been captured in relation to methodological, organisational, technological, constructional and occupational insights. Although more time consuming and challenging than common practice, there is a particular convergence on two points namely the transferability of the skills gained into future developments and the recognition of the added value of the final end products.

### Learning points

#### Methodological

- Standardised MV commissioning process
- Mandatory annual duct flow measurements
- Design replicability
- Location of MVHR
- Knowledge transfer architect-contractors
- Partnership, quality, and attention to detail in the realisation process
- New performance requirements, both energy and health
- Collaborative value of partnership arrangements
- Clear communication within the design team
- Communication design team-contractor
- Building design with people in mind
- Identify back up design strategies
- Identify design mitigation actions
- Effective client-architect-contractor communication
- Agreements to be made prior to site
- Shared agenda and sustainable targets from the project’s outset
- Getting the partners around the table as early as possible
- Understand in advance design, installation and supply chain requirements of new systems and technologies
- Undertake intensive research and development
- Fabric first approach
- Sort out details during the design phase
- Improved attention to space requirements for systems in the initial design
- Shared holistic approach to major changes
- Need for more detailed design specifications for installation and commissioning

#### Organisational

- Designed and actual energy use gap
- Rethinking on ventilation/ heating
- Handover best timing
- Exhaust Air Heat Pumps not appropriate for social housing
- Benefits of Passivhaus framework and processes
- Passivhaus reliability
- Passivhaus benefits on IAQ
- Underestimated extra-effort
- Worthwhile extra-effort
- Transferability of the skills acquired
- Trained service providers
- Resource constraints faced by training opportunities
- Service providers to motivate environmentally responsible behaviour
- Feeling of fulfilment and satisfaction
- Communication contractor-sub contractors
- Raise the bar for future projects
- Too ambitious goals set
- Risk understanding, communication and management
- Strategic value of collaboration
- Soft landings
- BPE evidence in support of remedial works requests to sub-contractors
- Revised processes in other developments
- Pro-actively manage responsibilities in the delivery of sustainable housing instead of delegating to developer/contractors
- Transferable skills for future housing developments
<table>
<thead>
<tr>
<th>Technological</th>
<th>Constructional</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Under-performance of MVHR systems</td>
<td>▪ Construction rigorously aligned with design</td>
</tr>
<tr>
<td>▪ Building diagnostics</td>
<td>▪ Minimise as-built variations from design</td>
</tr>
<tr>
<td>▪ Monitoring-based fine tuning</td>
<td>▪ On-site inspections as per approved design</td>
</tr>
<tr>
<td>▪ Heating controls should be suitable for residents</td>
<td>▪ Accredited M&amp;E installers</td>
</tr>
<tr>
<td>▪ MVHR need for improved design specifications (rigid ductwork, summer</td>
<td>▪ Robust management of the overall construction process</td>
</tr>
<tr>
<td>bypass and units sizing) and installation (on-site clerk of work)</td>
<td></td>
</tr>
<tr>
<td>▪ BPE as effective building diagnostics tool to verify and improve building</td>
<td></td>
</tr>
<tr>
<td>performance</td>
<td></td>
</tr>
<tr>
<td>▪ Critical evaluation of control mechanisms and technology level in place</td>
<td></td>
</tr>
<tr>
<td>▪ Reconsider the use of more conventional heating and ventilation systems</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Occupational</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ In-use monitoring</td>
</tr>
<tr>
<td>▪ Environmentally responsible occupants</td>
</tr>
<tr>
<td>▪ Forgiveness factor</td>
</tr>
<tr>
<td>▪ Review future handover practices</td>
</tr>
<tr>
<td>▪ Hold regular meetings with residents association to identify problems</td>
</tr>
<tr>
<td>▪ Regular contact occupant-housing staff</td>
</tr>
<tr>
<td>▪ More effective occupant education</td>
</tr>
</tbody>
</table>

### Soft Landings

The final step of the analysis focused on a review of the Soft Landings approach. Of the 15 projects that have provided sufficient information to address this research question, 80% (12 projects) successfully provided evidence of the key principles underpinning the Soft Landings approach.
References


