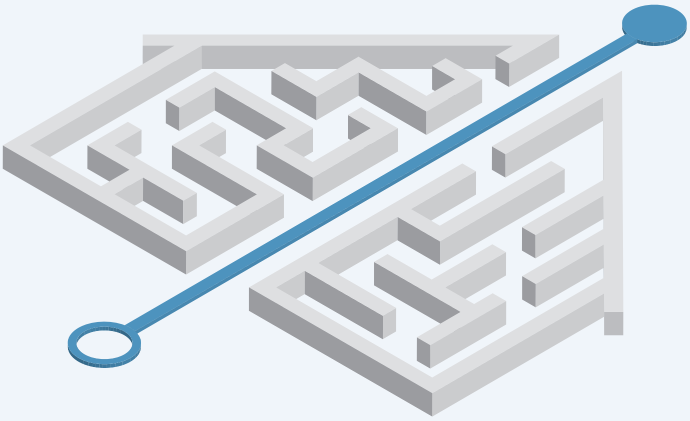

CLOSING THE GAP BETWEEN

DESIGN

&

AS-BUILT PERFORMANCE

END OF TERM REPORT

July 2014

APPENDIX F

ZERO CARBON HUB

The Zero Carbon Hub was established in 2008, as a non-profit organisation, to take day-to-day operational responsibility for achieving the government's target of delivering zero carbon homes in England from 2016. The Hub reports directly to the 2016 Taskforce.

To find out more, or if you would like to contribute to the work of the Zero Carbon Hub, please contact: info@zerocarbonhub.org.

Zero Carbon Hub
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76-86 Turnmill Street
London
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www.zerocarbonhub.org

This document contains Appendix F to the End of Term Report, which is available from www.zerocarbonhub.org

Published July 2014

APPENDIX F: ASSURED PERFORMANCE WORK GROUP PROPOSALS

As noted in the main report, more work is needed to develop and agree an approach to demonstrate the '2020 Ambition' of at least 90% of new homes meeting or performing better than their designed energy / carbon performance.

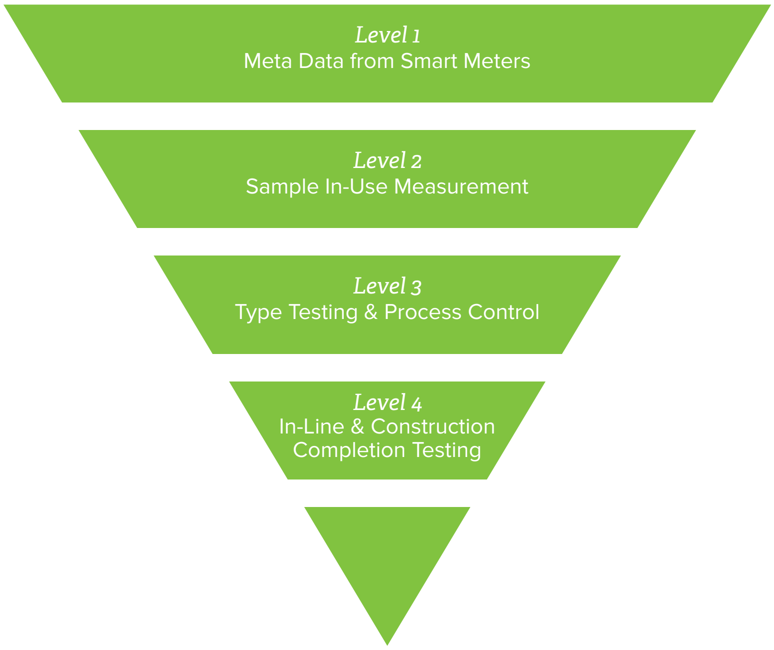
To further this aim and provide a basis for continued industry-wide discussions, the Assured Performance Work Group has proposed a tiered approach to data gathering, of which different levels may suit different housebuilders; for example according to their size. These are set out in Figure 1. This range of potential mechanisms would act to measure the size of the Performance Gap and provide relevant feedback to enable industry-wide continuous improvement. Each is considered in this appendix, with some appraisal of their strengths and weaknesses. There may be other methods which could be used, but those presented here are the ones which the Work Group explored in their discussions.

The Work Group concluded that a single approach may be neither necessary nor desirable, and that a combination could provide better flexibility for small to large housebuilders of every delivery type. This appendix has informed, and should be read in conjunction with, the 'Demonstrating Performance' section of the main report.[1] It should be noted that only relatively minor amendments and edits have been made to the material provided by the Work Group itself.

1. To download the End of Term Report please visit: www.zerocarbonhub.org/full-lib

Note that costings for each of the four suggestions have been carried out by Sweett Group. The method and calculations are included in Reference A, based on a mid-range cost. Within the main body of the report, a cost range is given, reflecting the variability of some aspects of the costing.

Figure 1. **Tiered Approach to Data Gathering**

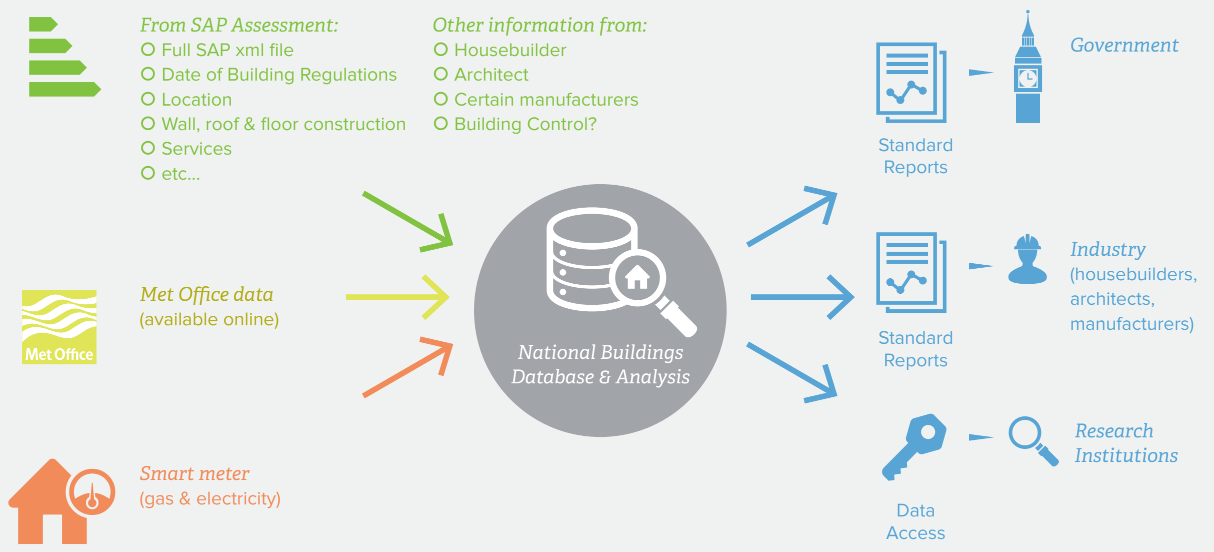


Level 1: As-built Performance Derived from Smart Meter Gathered Meta Data

Many new homes are being fitted with smart meters, and the Department for Energy and Climate Change aims for these to be fitted to all homes by 2020. The resulting data on energy use could be normalised to derive as-built performance, using algorithms that combine metered energy use with design performance data of the homes and actual weather data (see Figure 2). Where the build volumes are high enough, this could be refined to an individual housebuilder or to understand the general performance of specific types of construction.

This data is already being collected, making it a relatively easy and inexpensive approach to implement. It is based on actual performance of all homes, so is a robust approach, and provides feedback to the industry in a reasonably short timescale. On the other hand, the granularity of the information is poor, providing only basic clues to explain why some houses are underperforming. There are challenges around removing the influence of occupants from the data being gathered, for which very robust algorithms would need to be developed. Research on this is underway at universities and by industry. The data provided will highlight outlying performance across groups of homes, identifying particular construction types or house types. It will not however be able to identify why those properties are underperforming, for which other data streams are needed. In addition, really meaningful data may take several years to collect; the data collected would mix regulated and non-regulated loads; and not all households may agree to have smart meters fitted.

Figure 2. **Deriving As-built Performance from Smart Meter Gathered Meta Data**



Costs

This approach is estimated to cost between £2 and £4 per new dwelling, based on expenditure to develop the algorithms, server hosting and software support. More details on how these figures were derived are contained in Reference A.

To develop this approach further, a number of other questions would need to be answered, regarding ownership of the data, data protection issues and the level of confidence in the results. The table below summarises the strengths, weaknesses and resulting questions identified by the Work Group. Those of particular concern are in bold.

STRENGTHS	WEAKNESSES	QUESTIONS
Simple technical implementation	**Low level of granularity / accuracy**	How would the SAP software generated files and additional upload process be handled?
Output data from SAP allows analysis to be scaled to cover 90% of the population	Does not identify whether SAP assumptions are correct	Where would the data be located, who would own it and who would have access to it?
Estimated cost: £2-£4 per dwelling	**Only highlights the gap, with basic clues on the cause**	Is there an opportunity for an audience specific dashboard?
Robust approach (based on actual performance)	Privacy re-assurance & householder agreement needed	How will smart meters be installed and accessed?
Feedback can begin after one year	Meaningful sample data after 2-3 years	What data protection issues are there?
All dwellings are included	**Mixes regulated and non-regulated energy:** the latter is not part of the zero carbon definition and would need to be factored out	**What is the level of confidence in the results?**
	Algorithms needed to disaggregate the impact of weather & occupant behaviour	**When are smart meters rolled out to new build homes?**

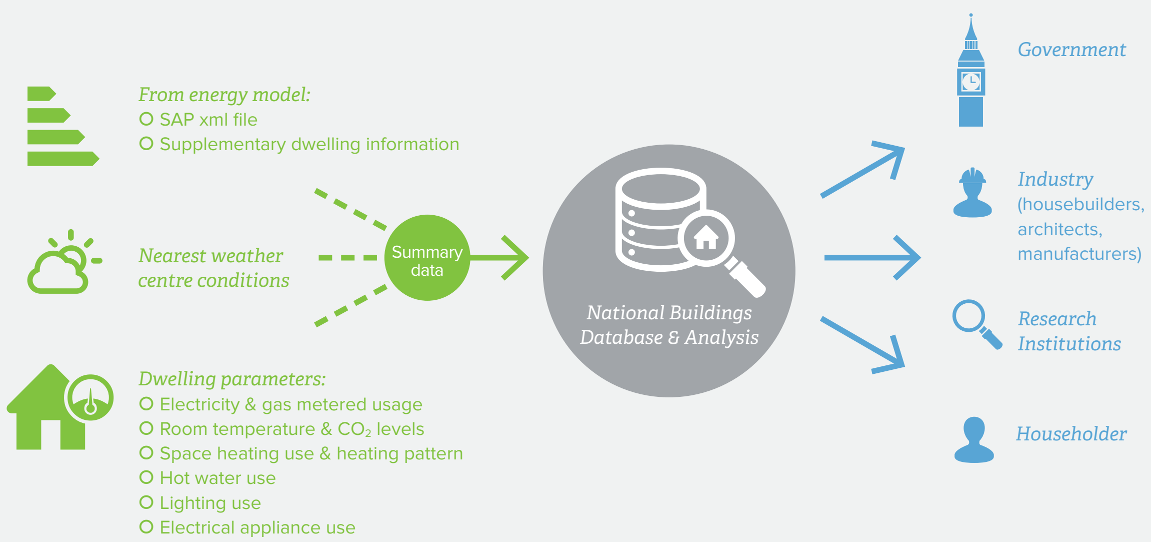
Level 2: As-built Performance Derived from Sample In-Use Measurement

For this method, a proportion of new homes would be fitted with monitoring equipment, to record main room temperatures, space heating, hot water demand, electricity use and so on. The actual energy use measured by the monitoring equipment would need to be normalised for standard weather and occupancy conditions so it can be compared to the property's as-built SAP calculations (see Figure 3). In comparison to the Meta Data approach (Level 1), this data stream would provide a more detailed understanding of which aspect of the property's energy performance is more likely to be creating a Performance Gap (e.g. space heating, water heating, etc).

The analysis would be automated, with standard reports generated to provide normalised performance feedback. This would be useful to: the housebuilder on how their homes perform; the home owner on how they are using the home; and the Government on how types of homes are performing.

This approach aims to combine the relatively low costs and minimal disruption to construction of the meta data approach, with the granularity and disaggregation of energy use of in-line and construction completion testing (Levels 3 & 4). However, no meaningful results would be provided until at least six months after monitoring starts and householders would need to consent, with reassurances of their privacy.

Figure 3. **Deriving As-Built Performance from Sample In-Use Measurement**



Costs

This approach is estimated to cost between £12 and £18 per new dwelling, based on 1 in 300 homes being fitted with monitoring equipment and the results analysed. More details on how these figures were derived are contained in Reference A.

The table below summarises the strengths, weaknesses and resulting questions identified by the Work Group. Those of particular concern are in bold.

STRENGTHS	WEAKNESSES	QUESTIONS
Provides a strong and cost effective on-going learning loop	**Reliant on sensor reliability and ability to transmit data reliably via the internet**	Where is the performance information held?
Has the potential to disaggregate (via measurement) regulated and unregulated energy use	**Householder agreement required and privacy reassurance needed**	**What level of repeatability of method and reproducibility of results can be achieved?**
Estimated cost: £12-£18 per dwelling	Needs at least 6 months of data for meaningful results / information	How would the sample dwellings be chosen and who would oversee this?
Can be combined with process control to reduce testing frequency	The algorithms need to be developed and the concept needs proving	
Good resulting granularity and strong clues as to areas of weakness should they arise		
Provides useful information and feedback to the householder as to their use of energy and areas they could optimise their use		
Effective for both high and low volume housebuilders		
Relatively easy to test randomly selected dwellings as testing equipment can be readily retrofitted		

Level 3: As-built Performance from Type Testing and Process Control

Under this approach, current and yet to be developed testing techniques would be used to refine prototypes and fully understand how they perform in energy terms, for both fabric and services systems. This data then informs the development of process controls, which target the most critical stages of design and construction so that wide-scale testing is not required in the field (see Figure 4).

The ‘types’ analysed through prototyping does not refer to a particular dwelling form such as a mid-terrace / detached or sales name such as ‘Chatsworth’ / ‘Cheney’; it instead represents a combination of systems, for example, the wall construction, roof form, floor system and air tightness approach. Most housebuilders have a more limited range of homes when expressed in these terms.

Each of these construction types would be tested to provide feedback on its performance and any potential risks from the underperformance of key variables. The range of tests currently available for fabric performance is limited, although there is considerable research interest in this area, as detailed in Appendix D ‘Testing Work Group Proposals’. Based on the test results, the construction type would then be refined accordingly, by improving the design; adjusting systems and products; or implementing further process control measures.

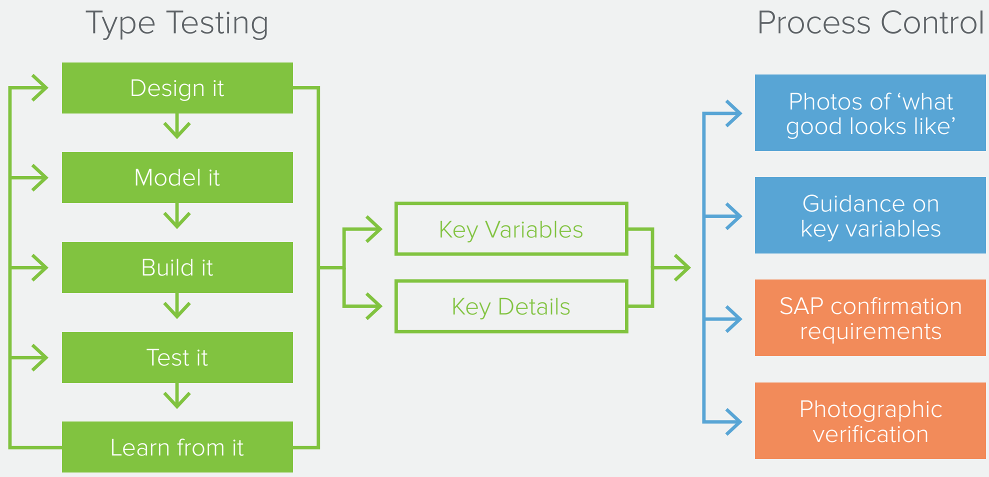
A process control system would be in place to ensure that the energy performance of the type test is consistently achieved. This could take the form of a smartphone / tablet ‘app’, which would provide guidance on correct installation and commissioning, as well as photos of how each element should ideally look. It would act as quality control to ensure that the energy performance tested during the type test(s) is repeated on subsequent dwellings built, reducing the need for confirmation tests.

Processes can drift and performance dependences are rarely fully understood, so some ongoing in-process or construction completion audit sampling tests would be needed, based on those applied to the type test, albeit at a reduced level compared with a scenario where a formal process control approach was not taken.

The ‘type test and process control’ approach suits a larger housebuilder model best where numbers of each 'type' are greater and the infrastructure to develop appropriate process control exists. However, systems suppliers or merchant groups may also develop and sell packaged solutions to their customers which have already been type tested and include process control.

Research would be needed to identify how much of the market this would therefore apply to, as well as the scope of the ‘types’, consideration of apartments and a clearer understanding of exactly how the process control would work.

Figure 4. **Type Testing and Process Control**



Costs

This approach is estimated to cost between £25 and £30 per new dwelling, based on type testing of 1 in 1000 new homes, development and management of a process control app and audit sampling of 1 in 500 completed homes. More details on how these figures were derived are contained in Reference A.

The table below summarises the strengths, weaknesses and resulting questions identified by the Work Group. Those of particular concern are in bold.

STRENGTHS	WEAKNESSES	QUESTIONS
Helps address multiple issues identified	**Most suited to build types that are produced in significant volumes**	How exactly is 'type' defined?
Provides a strong and rapid initial learning loop	**Without supplementary construction completion testing the approach is vulnerable to process drift**	Where is the performance information held?
Estimated cost: £25-£30 per dwelling	May require web connectivity on site, depending on the quality assurance approach adopted	How much of the market would this apply to? Would it be useable both by volume housebuilders and for volume standard systems used by medium and small housebuilders?
All homes can be improved through rigorous process control of critical variables	When system elements within a house 'type' are changed, testing may need to be repeated	**What level of confidence does it give that the performance of the test home(s) will actually be replicated in all subsequent homes built using the quality control process?**
Process control element reduces the level of construction completion testing needed	Represents an additional cost, especially including supplementary construction completion testing, although this cost may be offset by reduced defects generally	**How can apartments be reliably tested?**

Level 4: As-built Performance Calculated from Sample In-Line Tests / Construction Completion Tests

Unlike air permeability, it is not currently feasible to test / measure the energy performance of every dwelling built, either in-line or at the end of construction. Existing tests and protocols would be unaffordable and impractical on such a scale. Fabric related thermal tests are only viable during colder winter periods and therefore have significant negative impacts on delivery timescales.

Tests and protocols need significant development to ensure reliable and comparable results. It is considered that as-built performance should be calculated on a statistically significant sample of dwellings, representing typical production, rather than through individual testing of every new home.

The development of improved test methods and protocols is recommended in Appendix D 'Testing Work Group Proposals', which would provide a better range of less expensive and lower impact approaches to understand the performance of both fabric and services systems. If these were to be used without any process control system, a high sampling rate would be needed, in order to achieve a reasonable degree of confidence. This rate would depend on the level of process variability typically experienced, as well as the confidence in effective random sampling. Analysis of actual results measured would ultimately determine the testing frequency.

This approach would be straightforward to understand, prevents process drift and provides a strong feedback loop. However, the frequency required and complexity of such tests would place significant costs and programming problems on the industry.

Costs

This approach is estimated to cost between £60 and £80 per new dwelling, based on 1 in 50 homes undergoing a range of services tests and a whole house heat loss test. More details on how these figures were derived are contained in Reference A.

The table below summarises the strengths, weaknesses and resulting questions identified by the Work Group.

STRENGTHS	WEAKNESSES	QUESTIONS
Helps address majority of 'Cleared for Action' issues, as identified in the ***Evidence Review Report***	Significant additional cost from frequency and cost of testing. Estimated to be £60-£80 per new dwelling	What would the in-line and construction completion tests consist of?
Strong feedback loop	High frequency of testing needed	What frequency of testing is needed? This may be based on process variability measured.
Prevents process drift	Limitations of testing methods may make it only appropriate to homes completed in the winter months	Where would the performance information be held?
Easy to understand	Likely to have some impact on the construction / sales timeline	What is the level of confidence?

Conclusions and Recommendations

A mechanism is needed to measure performance, so that the housebuilding industry can understand the Performance Gap baseline, demonstrate its progress on the 2020 Ambition and develop a feedback loop to drive ongoing improvement.

The Work Group concluded that none of the approaches described above is a panacea and that all have strengths and weaknesses. It is recognised that risk-based process quality control will be critical in achieving the ambition at the lowest cost. However, some measure of outcome performance is required to provide the information on which to demonstrate performance and trigger action if performance is outside the expected tolerance. Different approaches work better for different housebuilding models and have different costs. Ultimately a single approach is neither necessary nor desirable, so instead of adopting a single mechanism, industry should combine different approaches to create a system that is equally applicable to all housebuilders. For large national companies with standardised products, combining type testing with process control and limited in-line and construction completion testing may be best. For small bespoke housebuilders, meta-data or in-use derived performance might provide a more affordable and useful approach.

REFERENCE A: EXPLANATION OF THE COSTING

Sweett Group quantified the costs of the proposals put forward by the Assured Performance Work Group. This Reference text provides detail on the approach taken and figures used in each of the costing analyses, detailing the following:

- Critical variables;
- Specific assumptions;
- Approach;
- Potential cost reductions over time;
- Tables of cost build-up.

There may be areas where further development of the ideas or more information is needed. Any further iterations of the costing exercise would therefore provide a more accurate and a reliable source for the industry. Note also that the cost tables presented below illustrate the cost build-up for a mid value of the cost ranges presented in the main appendix.

1.0 As-built Performance Derived from Smart Meter Gathered Meta Data

Critical Variables

- Time and resources needed to develop and maintain software.

Specific Assumptions

- Assumed cost and installation of smart meter is not an additional cost as it would be installed anyway, as per the Government initiative.
- One smart meter is required per house built (as the equipment cannot be reused).
- Access to SAP models for each home will be readily available.
- Any data protection issues have been overcome.

Approach

The approach to costing the proposed Meta Data solution is based on, and associated with, algorithm development and maintenance/support.

This is because it has been assumed that under the Government initiative to install new 'smart' meters in every household in the UK by the year 2020, the equipment cost – i.e. smart meters – would be incurred elsewhere. It is therefore not additional as a result of the implementation of this proposal.

The algorithm development and maintenance / support has been calculated in the same way as the costing of the algorithm for the 'As-built Performance Derived from Sample In-Use Measurement' methodology, i.e. based on the human resources required to develop the software, the time taken to develop the software and the salary/fees of the professionals. There is also an ongoing cost for data access to the smart meters and the SAP xml files.

Potential Cost Reductions over Time

Cost reductions over time will be realised due to the one-off nature of the software development. Subsequent to year one, the only costs associated with the software will be the ongoing development and maintenance / support charges, which will be significantly less than the initial investment to develop the software.

Tables of Cost Build-up

Totals

Total cost per assessment	**£3.03**
Total cost per house built	**£3.03**

Number of houses built per year: 100,000

Algorithm

Number of houses built per year		100,000	
DEVELOPMENT			
Time		0.5	year(s)
Team size		12	people
Av. annual salary		£55,000	
Commercial markup		25%	
	Total development cost	**£412,500**	CapEx
	Development cost per assessment	**£0.69**	
	Development cost per house built	**£0.69**	
ONGOING CHARGES			
Server hosting		£10,000	p/a
Software support		£19,250	p/a
General support		£55,000	p/a
Data access		£150,000	p/a
Annual cost		£234,250	OpEx (p/a)
	Total ongoing costs	**£1,405,500**	OpEx (total)
	Ongoing cost per assessment	**£2.34**	
	Ongoing cost per house built	**£2.34**	

Note: It is assumed that the cost and installation of smart meters is not additional as it would be installed under the Government initiative

2.0 As-Built Performance Derived from Sample In-Use Measurement

Critical Variables

- Cost of equipment;
- Testing intensity (number of tests required per house built);
- Lifespan of equipment;
- Length of test;
- Time and resources needed to develop and maintain software; and
- Time and resources needed to install and maintain installation of equipment.

Specific Assumptions

- Assumed cost and installation of a smart meter is not an additional cost as it would be installed anyway, as per the Government initiative.

Approach

The list of equipment required is as follows:

- Smart meter
- Environment sensors
- Heat meter
- Data logger
- Light meter
- Weather station

An assumption has been made that equipment could not be recovered. Therefore, monitoring would take place over two years, then the household would be allowed to keep the equipment and monitoring would stop. So, each equipment bundle is only used once, resulting in one equipment bundle being required per test.

In addition to this there is the cost of developing and maintaining the algorithm employed to manage the data. This has been calculated based on the human resources required to develop the algorithm, the time taken to develop the software and the salary / fees of the professionals. A notional 'commercial markup' has been incorporated into the calculation to account for profit margin of the company commissioned to develop the algorithm. There is also the ongoing cost of the server hosting, software support and data access to the smart meters and SAP xml files.

Potential Cost Reductions over Time

Cost reductions over time will be realised due to the one-off nature of the algorithm development. Subsequent to year one, the only costs associated with the algorithm will be the ongoing development and maintenance / support charges, which will be significantly less than the initial investment to develop the software.

Tables of Cost Build-ups

Totals

Total cost per assessment	**£4,376**
Total cost per house built	**£14.62**

Number of houses built per year: 100,000

In-use measurement

EQUIPMENT (KIT BUNDLE)	COST		QUANTITY	TOTAL
Smart meter *(to be installed anyway)*	£-	per item	1	£-
Heat meter	£300	per item	2	£600
Light meter	£50	per item	1	£50
Environment sensors (HOBO U12)	£80	per item	4	£320
DataLogger	£100	per item	1	£100
		Equipment kit bundle total:		**£1,070**

Number of years	6	
Measurement intensity	0.003	
Lifespan of equipment	2	year(s)
No. assessments required per year	334	p/a
Total number of assessments	2,004	
Total number of kit bundles required	2,004	
Equipment cost per assessment	**£1,070**	
Equipment cost per house built	**£4**	

TIME		
Set-up time	1	day(s)
Visits and analysis time required	6	nr
Length of visit and analysis	0.5	days
Day rate of professional	£400	per day
T&S	£75	per vsit
Time cost per assessment	**£1,900**	
Time cost per house built	**£6.35**	

TOTALS		
Equipment and time cost	£2,970	per assessment
Equipment and time cost	£9.92	per house built
Commercial markup	25%	
Equipment and time cost per assessment	**£3,713**	
Equipment and time cost per house built	**£12**	

Algorithm

DEVELOPMENT			
Time		1	year(s)
Team size		6	people
Av. annual salary		£45,000	
Commercial markup		25%	
	Total algorithm development cost	**£337,500**	
	Algorithm development cost per assessment	**£168**	
	Algorithm development cost per house built	**£0.56**	

ONGOING CHARGES			
Server hosting		£10,000	p/a
Software support		£45,000	p/a
General support		£110,000	p/a
Data access		£501	p/a
Annual cost		£165,501	OpEx (p/a)
	Total ongoing cost	**£993,006**	OpEx (total)
	Ongoing cost per assessment	**£496**	
	Ongoing cost per house built	**£1.66**	

Note: It is assumed that the cost and installation of smart meters is not additional as it would be installed under the Government initiative

3.0 Type Testing and Process Control

Critical Variables

- Cost of equipment;
- Equipment lifespan;
- Testing intensity (number of tests required per house built);
- Duration of each test;
- Scope of professional input; time to undertake each test;
- Fee of the professional undertaking the test;and
- Cost to develop Process Control 'app', with related ongoing charges.

Specific Assumptions

- Three 'assessments' are done per 'type test' – each assessment being used to refine three progressive iterations in order to fully test a complete 'type'.
- During these iterations, two full-time staff are required for three months.
- The type testing will be undertaken on 1/1000 homes.
- The audit sampling will be undertaken on 1/500 homes.

Approach

There are three aspects to consider when costing 'type testing and process control'. These are as follows:

1. Type testing iterations: this has been based on the construction completion test, as described below in Section 4 (As-built Performance Calculated from Sample In-Line Tests / Construction Completion Tests). For the sake of costing, it is envisaged that the type testing process would require three tests (of the 'construction completion' format) for the different iterations of each construction type, in order to refine each design to the appropriate level of performance. It is expected that type testing would be undertaken on 1/1000 houses.
2. Audit sampling: this is required as a 'check-up' to ensure that the standard of performance reached as a result of the type testing has been maintained via the process control. It is expected that this would be undertaken on 1/500 homes.
3. Process control app: it is proposed that a process control app be used as a means of process control when delivering the 'types'.

Type testing iterations

As mentioned, the iterative testing has been assumed to be based on the construction completion testing. As such, the equipment costs and number of tests / equipment bundle figures were taken directly from the construction completion testing calculations / figures. Again, these are detailed below in Section 4.

The number of ‘type tests’ conducted each year is the result of the number of houses built per year and the testing intensity. Given that an ‘equipment bundle’ can only undertake a certain number of tests per year (resulting from the time taken to undertake each test, and the time at which tests can be undertaken), the total number of equipment bundles can be determined that are required in order to complete the required number of tests.

This can then be multiplied by the cost of each equipment bundle in order to get the total cost. This in turn can then either be divided by the total number of assessments or the total number of houses built (during the lifespan of the equipment) in order to normalise the data.

The reason for normalising the data by calculating a cost ‘per house built’ is that because the benefits (i.e. the learning) of the type testing will be shared between each house built, it is appropriate that the costs should be shared also.

It has been assumed that to complete each type test would require the services of two professionals for three months full-time. This, again, was normalised to give costs per assessment and per house built.

Audit sampling

The equipment costs for the audit sampling were calculated in almost exactly the same way as the type testing iterations. The only differences were that only one test was required (rather than three) and that the testing intensity was 1/500 (rather than 1/1000). This is the frequency assumed necessary to be confident that the process control operates properly.

The time costs, however, were calculated in the same way as the time costs for the standalone construction completion test methodology, detailed below in Section 4. That is to say that the total time cost is a function of the: set-up and take-down time; number of visits required; length of visit; day rate of professional; and travel and subsistence.

Process control app

Defining the costs associated with the process control app followed the same process as for defining the costs associated with the algorithm of the Meta Data.

There are two parts to the costs:

1. The one-off development costs; and
2. The ongoing maintenance and support costs.

The cost for the one-off development is a result of: the time taken to develop the app; the size of the team required to develop the app; the average annual salary of those employees; and an allowance for a commercial markup to cover profit.

The ongoing costs cover the server hosting and the cost of one full-time staff (equivalent) for training and support / maintenance of the app.

It is assumed that the app would be used on each and every house built, rather than only on the houses undergoing testing, so the cost is normalised per house built.

Potential Cost Reductions over Time

No potential cost reductions over time have been identified at this stage.

Tables of Cost Build-up

Totals

Total cost per assessment	**£25,031**
Total cost per house built	**£27.90**

Number of houses built per year: 100,000

Type Testing

TYPE TESTING ITERATIONS	WHOLE HOUSE HEAT LOSS TEST	BOILER	VENTILATION	TOTAL
Cost of equipment	£2,690	£70	£250	£3,010
Number of tests / kit bundle / year	4	150	150	
No. iterations per test	3	nr		
Testing intensity	0.001			
Timeframe/ Lifespan of equipment	6	years		
No. tests conducted per year	100			
No. assessments required per year	300			
Number of kit bundles required	69	2	2	
Total cost of equipment	£185,610	£140	£500	£186,250
Equipment cost per type test / assessment	**£309.35**	**£0.23**	**£0.83**	**£310.42**
Equipment cost per house built	**£0.31**	**£0.0002**	**£0.001**	**£0.31**

TIME		
Duration of each iteration test	0.25	year(s)
Team size	2	people
Av. annual salary	£45,000	
Cost of time per type test	**£22,500**	
Cost of time per house built	**£22.50**	

Equipment & time cost per type test	**£22,810**
Equipment & time cost per house built	**£22.81**

Process Control App

DEVELOPMENT		
Time	0.5	year(s)
Team size	5	people
Av. annual salary	£50,000	
Commercial markup	25%	
Total development cost	**£156,250**	CapEx
Development cost per house built	**£0.26**	

ONGOING CHARGES		
Server hosting	£10,000	p/a
Technical support & Training	£50,000	p/a
Annual cost	£60,000	OpEx (p/a)
Total ongoing cost	**£360,000**	OpEx (total)
Ongoing cost per house built	**£0.60**	per house built
Total Development & Maintenance cost	**£516,250**	
Development & Maintenance cost per house built	**£0.86**	

Audit Sampling

AUDIT SAMPLING	CO-HEATING	HEATING / HOT WATER SYSTEM TEST	VENTILATION SYSTEM TEST	TOTAL
Cost of equipment	£2,690	£70	£250	£3,010
Number of tests / kit bundle / year	4	150	150	
No. tests req'd	1	nr		
Testing intensity	0.002			
Timeframe/ Lifespan of equipment	6	years		
Houses built per year	100,000	nr		
No. assessments required per year	200			
Number of kit bundles required	46	2	2	
Total cost of equipment	£123,740	£140	£500	£124,380
Equipment cost per assessment	**£206.23**	**£0.23**	**£0.83**	**£207.30**
Equipment cost per house built	**£0.21**	**£0.0002**	**£0.001**	**£0.21**

TIME		
Set-up and take-down time	2	day(s)
Visits required	3	nr
Length of visit	0.5	days
Day rate of professional	£500	per day
Travel & subsistence	£75	per vsit
Time cost per test	**£2,012.50**	
Time cost per house built	**£4.03**	

Total equipment and time cost per test	**£2,220**
Total equipment and time cost per house built	**£4.23**

4.0 As-built Performance Calculated from Sample In-Line Tests / Construction Completion Tests

Critical Variables

- Cost of equipment;
- Equipment lifespan;
- Testing intensity (number of tests required per house built);
- Duration of each test;
- Scope of professional input;
- Time to undertake each test; and
- Fee of the professional undertaking the test.

Specific Assumptions

- It has been assumed that whole house heat loss tests can only be carried out in the winter months, i.e. 25% of the available days in the year.
- Heating and hot water system testing: For the purposes of costing, it has been assumed that a system consists of a gas combi boiler with radiators. Work Groups concluded that there is currently no recognised 'standard' test for establishing the in-use efficiency / performance of domestic boilers. As such, a logical test was devised for the purposes of the cost exercise, which involves measuring both the energy input and the energy output in order to determine the difference between the two, and therefore the efficiency of the system.
- The cost of gas and electricity meters has been excluded, as each property will have these installed as a matter of course.

Approach

The approach to costing construction completion testing needs to take into consideration a wide range of variables. A valid construction completion test needs to consider both building fabric and building services, which need to each be costed separately.

The building fabric has been assumed to be tested via a whole house heat loss test. The efficiency (and, therefore, the quality of installation) of the building services have been assumed to be tested by measuring the energy consumed, minus the energy output, therefore identifying the excess energy lost.

Building fabric: Whole house heat loss test

The first stage is to quantify the cost of the equipment required to complete the whole house heat loss test. The list of required equipment was taken from a Leeds Metropolitan University paper,[1] and the prices for the equipment were found online. The approved list of equipment is as follows:

- Temperature and RH sensors
- DataLogger
- Fan heaters
- Heat Flux sensors
- Circulation fans
- Extension leads
- Thermostats
- Weather station
- kWh meters
- Pyranometer

As the equipment is able to be used on multiple houses / tests, the total cost of this equipment will not be incurred for each and every whole house heat loss test carried out. The total equipment cost can therefore be distributed evenly between the total number of tests completed in the lifetime of the equipment, or by the total number of houses built in the lifetime of the equipment. An 'equipment bundle' will only be able to undertake a certain number of tests per year, and only last for a specific timeframe.

Given a defined total number of houses built per year, and a defined testing frequency, the number of tests required each year is also defined. Given this defined testing regime, a total number of 'equipment bundles' can be calculated that are required in order to fulfil the testing requirement.

The capital cost of the 'equipment bundle' is then multiplied by the defined number of 'equipment bundles' required to find the total cost. This can then be normalised by being divided by either:

- The total number of tests undertaken, or
- The total number of houses built in the lifetime of the equipment

The final element to consider when calculating the cost of a whole house heat loss test is the cost of the professional's time to undertake the test. This is determined by the day rate of the professional and the time devoted to the test and any additional miscellaneous costs. The time spent conducting the test will be a combination of set-up / take-down time and any interim visits required.

Building services testing

The process for calculating the costs of the building services tests is the same as for the building fabric, that is to say: there is the cost of the equipment to consider, the distribution of this cost over the lifetime of the equipment and the cost of the professional's time to undertake each test.

The services tests required have been costed based on a ventilation test and a heating and hot water system test; for the latter, it is assumed that the system consists of a gas combi boiler with radiators. Other services systems may be present in individual houses / developments, but are not deemed to be installed as 'standard' on the majority of homes. If other systems are present, then the same structure can be used to cost the testing regime.

Potential Cost Reductions over Time

No potential cost reductions over time have been identified at this stage.

1. Johnston, D., Miles-Shenton, D., Wingfield, J., Farmer, D., Bell, M. (2012) Whole House Heat Loss Test Method (Coheating) Available from http://www.leedsmet.ac.uk/as/cebe/projects/iea_annex58/whole_house_heat_loss_test_method (coheating).pdf

Tables of Cost Build-up

Totals

Whole House Heat Loss Test - per test	£2,645
Whole House Heat Loss Test - per house built	£53
Boiler Efficiency Test - per test	£406
Boiler Efficiency Test - per house built	£8.13
MVHR Efficiency test - per test	£407
MVHR Efficiency test - per house built	£8.13
Total cost per assessment	**£3,457**
Total cost per house built	**£69**

Number of houses built per year: 100,000

Whole House Heat Loss Test

EQUIPMENT (KIT BUNDLE)	COST		QUANTITY	TOTAL
Temperature and RH sensors	£70	per item	4	£280
Fan heaters	£100	per item	4	£400
Circulation fans	£50	per item	4	£200
Thermostats	£20	per item	4	£80
kWh meters	£30	per item	4	£120
DataLogger	£100	per item	1	£100
Heat Flux sensors	£250	per item	4	£1,000
Extension leads	£20	per item	4	£80
Weather station	£130	per item	1	£130
Pyranometer	£300	per item	1	£300
			Equipment kit bundle total:	**2,690**

Lifespan of equipment	6	years
Testing intensity	0.02	
Duration of test	21	days
No. tests required per year	2,000	
Total number of tests	12,000	
Number of tests / kit bundle / year	4	
Number of kit bundles required	460	
Total assessments in lifespan	26.11	
Equipment cost per assessment	**£103**	
Equipment cost per house built	**£2.06**	

TIME		
Set-up and take-down time	2	day(s)
Visits required	3	nr
Length of visit	0.5	days
Day rate of professional	£500	per day
T&S	£75	per vsit
Time cost per assessment	**£2,013**	
Time cost per house built	**£40.25**	

TOTALS		
Equipment and time cost	£2,115.62	per test
Equipment and time cost	£42.31	per house built
Commercial markup	25%	
Equipment and time cost per assessment	**£2,645**	
Equipment and time cost per house built	**£52.89**	

Building Services Tests

BOILER SYSTEM TESTING EQUIPMENT	COST		QUANTITY	TOTAL
Gas calorific value (input)	£-	per item	1	£-
Gas meter (input)	£-	per item	1	£-
DHW flow rate (output)	£50	per item	1	£50
DHW temperature (output)	£20	per item	1	£20
			Boiler system testing equipment Total:	**70**

Lifespan of equipment	6	years
Number of tests possible / kit bundle / year	150	
Testing intensity	0.02	
No. tests required per year	2,000	
Total number of tests	12,000	
Number of kit bundles required	14	
Average lifespan assessments	857.14	
Equipment cost per test	**£0.08**	
Equipment cost per house built	**£0**	

BOILER/HEATING SYSTEM	
Visits required	1
Length of visit	0.5
Day rate of professional	£500
T&S	£75
Time cost per assessment	**£325**
Time cost per house built	**£6.50**

TOTALS		
Total equipment and time cost	£325.08	per test
Total equipment and time cost	£6.50	per house built
Commercial markup	25%	
Equipment and time cost per assessment	**£406**	
Equipment and time cost per house built	**£8.13**	

VENTILATION TESTING EQUIPMENT	COST		QUANTITY	TOTAL
kWh meters (input)	£-	per item	1	£-
Fan speed (output)	£100	per item	1	£100
Air flow rate (output)	£100	per item	1	£100
Air temperature (before & after)	£50	per item	1	£50
			Ventilation testing equipment total	**£250**

Lifespan of equipment	6	years
Number of tests possible / kit bundle / year	150	
Testing intensity	0.02	
No. tests required per year	2,000	
Total number of tests	12,000	
Number of kit bundles required	14	
Average lifespan assessments	857.14	
Equipment cost per test	**£0.29**	
Equipment cost per house built	**£0.01**	

MVHR		
Visits required	1	
Length of visit	0.5	
Day rate of professional	£500	
T&S	£75	
Time cost per assessment	**£325**	per test
Time cost per house built	**£6.50**	per house built

TOTALS		
Total equipment and time cost	£325.29	per test
Total equipment and time cost	£6.51	per house built
Commercial markup	25%	
Equipment and time cost per assessment	**£407**	
Equipment and time cost per house built	**£8.13**	

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