



Monitoring energy and
carbon performance
in new homes



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Contents

Executive summary	3
1. Introduction	4
2. Monitoring approach	4
2.1 Frequency of recording	5
2.2 Frequency of measurement	5
2.3 Data collection strategy	6
3. Short-term measurements	7
3.1 Envelope airtightness	7
3.2 Mechanical ventilation system operation	7
3.3 Fabric insulation performance	7
3.4 Occupancy details	9
4. Long-term monitoring	9
4.1 Dwelling performance	9
4.2 Solar water heating	10
4.3 Photovoltaics	11
4.4 Wind turbines	11
4.5 Heat pumps	12
5. Climate data	13
6. Presentation of results	14
7. Co-operation from developers	15
8. Indication of monitoring costs	15
9. The impact of number of dwellings monitored	17
10. Further information	19

Monitoring energy and carbon performance in new homes

Executive summary

The Government has set a target for all newbuild homes in England to be zero carbon by 2016, and other countries within the United Kingdom have followed suit with their own challenging targets. This is an extremely challenging undertaking and requires a thorough and co-ordinated monitoring of the homes we build. In order to achieve it, we must take a scientific approach, monitoring the houses we build so we can learn from them and build the lessons into new designs.

In the past, monitoring projects have produced vast quantities of data from dwellings. However, it has seldom been possible to make comparisons of the relative merits of different monitoring approaches, mainly because results were never presented in a single, consistent format.

The Energy Saving Trust has developed a whole-house carbon and energy monitoring protocol to determine how the key features of new designs – such as enhanced airtightness, improved fabric insulation levels, renewable energy – contribute to the improved energy performance of the new designs.

This will enable developers and house builders to determine whether their homes perform as designed. The protocol is intended as a baseline for collecting information. It uses a standardised approach for both monitoring and reporting results, so different building techniques and renewable energy technologies can be usefully compared.

The Energy Saving Trust's protocol uses a combination of both short-term measurements and long-term monitoring and recognises the importance of robust climate data as well as consistent presentation. We also place a strong emphasis on robust data collection using the latest technologies.

- **Short-term:** 'One time' tests for elements such as airtightness, mechanical ventilation and fabric insulation are essential, even though they can be disruptive to occupants.
- **Long-term:** Testing the performance of dwellings and any renewable technologies over time must involve frequent monitoring over at least two heating seasons to provide robust data. Renewable technologies need to be measured at five-minute to ten-second intervals. Automatic, mains-connected, cabled monitoring with easily accessible data loggers is the preferred option.
- **Presentation:** Consistency is the key, with standardised data and measurements so meaningful comparisons can be made.

Developers are crucial to this new monitoring protocol. They will need to make properties available for one-time tests and co-operate with the requirements of long-term testing.

There is, of course, a cost for monitoring, but as the report shows, there are many opportunities for these to be spread out, for example by sharing sensors between technologies.

Finally, the report suggests that a sample size of 100 dwellings is needed to provide results that have a useful level of accuracy.

Monitoring energy and carbon performance in new homes

1. Introduction

This document outlines an approach to monitoring the energy performance of housing built to higher standards, principally in relation to the Code for Sustainable Homes. This forms part of an overall monitoring process that will also cover the design, building and operational phases, as well as addressing costs, 'buildability', occupant reaction and physical performance. In this document, we only discuss the monitoring of physical performance, which means energy consumption and carbon emissions. The key goals of this part of the monitoring process are to:

- Measure the energy consumption and carbon emissions of sample houses built to the new designs.
- Examine how this performance compares with a control group of houses.
- Determine how the key features of the new designs (enhanced airtightness, improved fabric insulation levels, renewable sources of energy) contribute to improved energy performance.

To choose a suitable control group, it is necessary to consider what would have been built without the Code for Sustainable Homes. This is most likely to have been dwellings built to current building regulations, so we use a sample of these to provide a baseline for the results.

We also need to know how renewable technologies perform when they are included in the design, and so understand their contribution to a house's overall carbon budget. Solar water heating, photovoltaics, wind turbines and heat pumps have been included thus far and it is hoped that the approach taken is sufficiently broad to allow further technologies to be readily added.

Previous monitoring schemes have produced a wealth of information, albeit from buildings of much lower performance than those considered here. It has, however, been difficult to make comparisons between different projects, so a great deal of potentially useful information has been lost. This document presents a standardised approach for both monitoring and reporting results, allowing for valuable comparisons into the future.

Over the lifetime of this document it is likely that there will be considerable changes in the technology available for gathering performance data in buildings. Particularly rapid advances are currently taking place in the areas of:



Figure 1: A collaboration between Osborne Homes and Raven Housing Association, the Mid-Street home is the first 100% affordable housing scheme to achieve level 5 of the Code for Sustainable Homes. The Energy Saving Trust is monitoring the energy performance of the dwellings

- Wireless communication between sensors and data logging equipment.
- Powering of sensors using locally available energy (so called 'energy harvesting').
- Internet enabling of measuring equipment to greatly simplify the data collection process.
- The use of smart meters to gather data in addition to fuel consumption.

Bearing in mind the pace of these developments, we do not set out to specify the types of equipment nor the ways in which it should be interconnected, powered or interrogated. Instead this document concentrates on the measurement requirements, including the resolutions, accuracies and recording rates which will be needed to ensure that the resulting data are useful.

2. Monitoring approach

The simplest approach to determining annual energy consumption and therefore carbon emissions is to take readings from energy meters at the start and finish of the monitoring year.

In practice there are many reasons for wanting to gather data more frequently than this. These centre around data robustness, the analysis of system performance and the normalisation of data.

Taking meter readings at the start and finish of the monitoring period is not robust, because the entire

Monitoring energy and carbon performance in new homes

outcome of the monitoring exercise hinges on just a handful of readings. If an error is made in a reading it will probably not be possible to detect it. And if a reading is missed or a meter malfunctions, it will not be possible to recover the information. Even more seriously, a malfunction which occurs part way through the year may go undetected, giving misleading results. Taking readings at more regular intervals means that 'rogue' data can be spotted, and analysis limited to the period for which the data is believed to be sound.

Any analysis of the performance of each type of system can only be assessed for consistency and repeatability if multiple data points are available. If data is only recorded annually, a conclusive analysis will only be available after many years.

Closely linked to system performance analysis is the issue of normalisation. For example, the weather in any particular monitoring year is unlikely to be wholly representative of the longer-term climate. In particular, it will not be the same as the climate data used when the performance is predicted in the Standard Assessment Procedure (SAP) calculation. To make comparisons with expectations it is therefore necessary to adjust the measured performance to determine what would have been measured had the climate been as assumed in SAP. This adjustment cannot be made based on annual data.

Consider the case in which a solar water heating system experiences reduced solar radiation over a particular monitoring year. If the reduction in radiation occurred in the summer, when the system was satisfying the whole hot water demand with some energy left over, it will have little effect. If on the other hand it occurred in winter, when the system was using all of the incident radiation, it will have a significant effect. It is therefore not possible to normalise the data if only annual total values are available.

2.1 Frequency of recording

There are major advantages associated with recording more frequently. The building fabric has significant time constants associated with it, and unless a complex dynamic analysis is to be made it is unlikely that data will be used at a frequency higher than weekly. This approach has the added advantage that occupant behaviour has a strong weekly component, and the use of data recorded at one-week intervals has the effect of averaging over one whole cycle of these disturbances.

Past experience has shown that the use of weekly energy and temperature data can allow the specific energy consumption of a dwelling to be characterised with useful accuracy over the course of one heating season. Weekly meter readings and weekly average internal and external temperatures therefore form the most basic level of monitoring that is consistent with the goals of this specification.

Other technologies have much shorter time constants than the building fabric. A solar water heating system may have storage for one (or at most two) days' consumption. A photovoltaic system has almost no dynamics associated with it, and a wind turbine is likely to respond to changes in conditions over a timescale of seconds. Recent projects have recorded data from both of these technologies at five-minute intervals. Heat pumps may have some thermal storage in the form of a buffer tank, but again the time constant is likely to be relatively short and a recording interval of ten minutes will produce useful information.

In general, data from any of these technologies can be analysed on a daily basis, and in many cases it may be possible to carry out the analysis over an even shorter timescale. Five-minute recording of all measured quantities is therefore the preferred form of data gathering for these systems.

2.2 Frequency of measurement

The electricity and heat meters commonly used for this type of application monitor continuously and



Figure 2: Photovoltaic inverter

Monitoring energy and carbon performance in new homes

produce an output pulse every time a given amount of energy has been delivered. These pulses are then counted by the data logger, ready for recording an energy total at whatever interval is chosen.

When analogue quantities such as temperature or solar radiation are measured, it is necessary to make those measurements at a speed high enough to capture all the information which is present in the constantly varying quantity. In the case of solar radiation, which can vary extremely rapidly, it is desirable to sample every ten seconds. In this case the measurements are then averaged over the recording period.

2.3 Data collection strategy

Data collection may range from manual readings of meters and temperature indicators, through to automatic recording using data loggers.

Manual data collection restricts the rate at which data can be recorded. In previous projects householders have been asked to take weekly readings from their utility meters. However this is the highest recording frequency which can be maintained over a whole year. Furthermore, some readings are inevitably missed or lost. Finally, there is always the possibility of error creeping into the readings as they are written down. In some projects, miniature temperature data loggers are used to record internal and external temperatures. However, their data capacity means that data had to be downloaded every few months, which means gaining access to the properties being monitored.

Many energy meters now have the ability to keep a limited historical record of consumption. If a meter is capable of holding weekly readings over a suitably long period then this may form a route by which very low-cost monitoring can be carried out. However, the data will not be available for analysis until after all the readings have been retrieved, and any problems arising will therefore not be detected until this stage.

'Smart' meters, whose data can be remotely downloaded, provide another possible way of acquiring consumption data. Some of these meters have the ability to accept inputs from additional sensors, although the range of inputs available is currently limited.

A dedicated centralised, automated data recording system solves all of the problems outlined above. If the data logger is housed in a (lockable) cabinet on

the outside of the house, it can be readily accessed to collect data. This can be done by connecting a laptop, or by simply exchanging a memory card. The latter option has the advantage that it can be carried out by a relatively unskilled operator. Mounting the data acquisition equipment outside the house also greatly simplifies any routine maintenance that may be required. In the case of a new house, an extra meter cupboard might form a very cost effective way of providing such an enclosure.

Using a centralised logging system also opens up the possibility of collecting the data using the mobile phone network. In this case it will be necessary to include in the budget a suitable modem, a network contract, and call charges. This has the advantage of enabling data to be collected regularly, and any problems can be fixed before a significant amount of information is lost.

The price paid for this level of convenience is the need to have connections from all sensors (power meters, heat meters, temperature sensors, etc) back to the centralised data logger. This can be done with wireless sensors, but these require a source of power, generally a battery which requires regular changing.



Figure 3: Exterior lockable cabinet

Monitoring energy and carbon performance in new homes

Power-line communication provides another way of communicating data back to a central point. However, both of these options are generally more expensive, and less reliable, than simply installing cabling between all sensors and the centralised data logger. In the case of new housing, the cabling can simply be incorporated into the electrical first fix procedure. For an existing property it may be more difficult to conceal cabling, and a wireless solution may prove more appropriate.

3. Short-term measurements

A number of aspects of performance can be determined from relatively short measurements of different aspects of building performance, often referred to as 'one-time tests'. In practice it may be desirable to repeat these tests after a building has been occupied for a period and allowed to 'settle in'. This will require the co-operation of the house occupants. An owner-occupier may welcome such repeat testing to determine that their house is still performing as intended. In the case of a tenanted property it is likely that the requirement for access for repeat tests will need to be built into the tenancy agreement.

The tests are typically completed within a day, although some, particularly those that relate to heat flows through solid elements, may take longer. The key feature of these tests is that they provide a snapshot measure of one aspect of building performance. In general, they are conducted in such a way as to provide information about the performance of the building itself, irrespective of climate or occupant behaviour. This is vital, as the short duration of each test does not allow a representative selection of climatic conditions to be captured.

3.1 Envelope airtightness

Envelope leakage testing is now a well established technique: indeed it forms part of the requirements for building regulations compliance. However, this process requires only that a relatively small proportion of the houses in any one development are tested. For the purposes of this investigation it is suggested that all monitored dwellings should be tested.

The costs associated with initial tests can to some extent be offset against costs which the developer would have incurred anyway in complying with the airtightness requirements of the building regulations.

It is suggested that this test is repeated after approximately one year, to detect any settling in effects. Each test will typically take about a half a day.

3.2 Mechanical ventilation system operation

Two key aspects of mechanical ventilation and heat recovery systems need to be measured: airflows and the electrical energy consumed to generate those airflows.

In general a measurement using a simple anemometer (usually based on a miniature vane or hot wire) inserted into a complex ducting arrangement will not provide a particularly good indication of the overall mass flow. A preferable system uses a hood which can be placed over an outlet grille, allowing system balance as well as the overall flow to be tested.

System heat recovery effectiveness is generally a function of flow rate and, to a lesser extent, operating temperatures. This could be measured in the field, but in general it will already have been defined by the system manufacturer and published as part of the system specification. Combining this information with measured flows and internal and external temperatures allows the energy and carbon benefit of the system can be calculated.

The electrical consumption of mechanical ventilation systems can be a key component in the overall carbon balance, and can vary widely depending on the ducting layout. It is therefore important that this is checked for each system. The measurement can be quickly made with a portable clamp power meter, or by temporarily plugging the system into a specially prepared power metering box.

As with airtightness, it is suggested that these tests are repeated after one year. The tests should again typically take no more than half a day.

3.3 Fabric insulation performance

The general approach to assessing fabric insulation centres around a co-heating experiment. Heaters are used to maintain a constant temperature within the building over a period of at least ten days. The energy input required to do this is measured, together with the mean temperature inside the building, and the external temperature. Usually, electric heaters will be used:

- They allow the heating energy to be easily measured.

Monitoring energy and carbon performance in new homes

- They are simple to control. In general temperature control to better than $\pm 0.2^{\circ}\text{C}$ should be attainable. In this way the impact of energy flows into and out of the building mass is minimised.

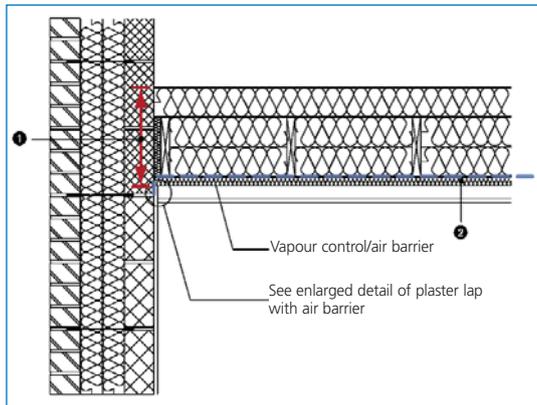


Figure 4: An Enhanced Construction Detail

The Energy Saving Trust has produced a set of Enhanced Construction Details (ECDs) to help housing professionals reduce heat loss as a result of thermal bridging. For more information visit 'Helpful Tools' at www.energysavingtrust.org.uk/housing

As well as minimising the effects of mass heat flows, the co-heating experiment ensures that there is a significant temperature difference driving the heat flows of interest. To this end it is tempting to elevate the internal temperature well above normal levels. This should generally be resisted, since the thermal conductivity of many insulants deteriorates with increasing temperatures, and the test soon becomes unrepresentative. For example, the conductivity of one popular foam insulation board increases by approximately 6% for every 10°C increase in mean working temperature.

A much better way to maintain a significant temperature difference between inside and outside is to carry the test out during the winter, when external temperatures are lower. However this may not always be practical, and in some cases an elevated internal temperature may have to be used in conjunction with a small correction for temperature dependency effects.

A further source of error in these tests is solar radiation. The impact of solar on the opaque

surfaces of a building decreases as the surface U-value decreases, and is likely to be minimal for the insulation levels being considered in this study. Windows may be shaded, often using a reflective sheet suspended on the inside. The desire to minimise solar effects is another incentive to try to carry this particular test out in winter. In situations where a building has very large glazed areas, an alternative approach may be to measure the solar radiation incident on the glazing during the test and incorporate it into the subsequent data analysis. In this way a solar aperture may be derived as well as a fabric heat loss, but the overall accuracy of the test is likely to be reduced.

If a co-heating experiment indicates that overall building heat loss is significantly different to the expected performance, a number of possible reasons must be considered:

- **Infiltration (unwanted sources of cold air leakage into the building):** the airtightness of the building fabric will already have been quantified by the leakage tests described in section 3.1, and particularly high or low values may offer some insight into unexpected building heat loss. If infiltration is suspected then a tracer gas test carried out during the co-heating period would confirm it.
- **Ventilation (desired sources of fresh air into the building):** this heat load should already have been quantified by the mechanical ventilation system tests described in section 3.2.
- **Insulation performance of solid elements:** it is proposed that these elements are separately monitored for the duration of the co-heating experiment using local heat flux sensors. This will allow any rogue elements to be identified. The fact that the internal temperature is being held constant during the test will greatly improve the accuracy and repeatability of these measurements. The technique is well established for opaque elements, but is less reliable for windows. However, failures in window systems are much more likely to be due to poor seal performance than to the U-value of the glazing. This should already have been detected by the airtightness tests described in section 3.1.

Continued...

Monitoring energy and carbon performance in new homes

- Thermal bridging through edge and corner details:** if none of the above explain excessive fabric heat loss, it may be that edge detailing has not been adequately implemented. In this case thermography may be used to check for high heat loss paths. Once again, the fact that internal temperatures are being maintained at a constant elevated value will significantly enhance the value of such a test.

- Level of occupancy, in terms of numbers of adults and children.
- Employment details of occupants.
- Broad assessment of energy use patterns.
- Level of energy-consciousness amongst occupants.

Like the physical measurements described above, the questionnaire should be run at least twice, to allow any changes in occupancy over the monitoring period to be assessed.

Because a co-heating test requires that the dwelling is unoccupied for a period of at least two weeks, it is difficult to repeat it after the building has been occupied for a period. However, the most likely sources of long-term deterioration in whole-house heat loss are increased infiltration (due to drying out) and changes in performance of mechanical ventilation systems. Both of these will be detected when envelope airtightness and mechanical ventilation system operation are re-tested.

3.4 Occupancy details

Details of dwelling occupancy can be obtained with a simple questionnaire. Although the specification of such a questionnaire is outside the scope of this document, it is likely that it would include questions to determine:

4. Long-term monitoring

4.1 Dwelling performance

As discussed in the introduction, the energy consumption and carbon emissions of a dwelling can be determined from gas, electricity and water meters. The key variables which drive fabric heat loss, and hence heating energy consumption, are internal and external temperatures. If ventilation proves inadequate, occupants may be forced to open windows, increasing the building specific heat loss. The most probable indicator of inadequate fresh air supply is likely to be excessive humidity levels, and for this reason a humidity measurement has also been included.

Table 1 below summarises the quantities that need to be measured in order to establish the energy consumption and therefore emissions from the building's fabric and services.

Table 1: Monitoring requirements: dwelling fabric

Performance indicator(s)	Key drivers	Measurements
Building gas consumption	Internal temperature	Heating energy consumption (gas, electricity, oil, biofuel, etc)
Building electricity consumption	External temperature	Electricity consumption
Building water consumption		Water consumption
		Internal temperature
	External temperature	
		Internal humidity

Monitoring energy and carbon performance in new homes

In the majority of cases it is assumed that the consumption information required will be available from utility company meters. If, as is likely, an automated data collection system is used, it will be necessary to ensure that these meters have outputs (generally a simple pulsed output) that communicate with the chosen data acquisition system.

Biofuels (most frequently wooden pellets) present particular measurement problems. If the boiler or stove has an automated feeding system then it may be possible to monitor the amount of time for which that system is operating. In any case it will certainly be necessary to obtain from the householder records of the rate at which pellets are used. Fortunately, the carbon cost of wood pellets is small, so uncertainties in the quantity used will have relatively little impact when determining overall emissions.

In the case of internal temperatures, the general principle of introducing redundancy can be extended to include the use of multiple sensors. As well as allowing a better determination of average temperature, this approach has the further advantage that a sensor failure will not result in total data loss. Past experience suggests that three sensors, located upstairs, downstairs and in the kitchen area will provide a good average.

It is suggested that a single humidity measurement is made in the main living area. There are a number of reasons for this. Both kitchens and bathrooms will be equipped with the ability to discharge excess humidity rapidly, either with a ventilation fan or a boost facility on a whole-house mechanical ventilation system. Bathrooms are now generally finished to withstand high moisture levels without damage, with some even described as 'wet rooms'. The final reason is practical: the type of sensor normally used to make this measurement is likely to give significant errors if exposed to humidities close to 100%, and may eventually cease to function all together.

4.2 Solar water heating

The appraisal of solar water heating systems is complicated by the wide variety of different systems available. Some systems use the collectors to heat water in a separate preheat tank, whereas others heat the main hot water cylinder directly, effectively using the lower section of the tank as a preheat volume. Other systems circulate the hot water supply directly through the collector panel.



Figure 5: Solar thermal collectors

The way in which systems are powered also varies widely. Many systems use a conventional domestic heating pump, typically consuming about 40 Watts, to circulate water through the collectors. In this case the 'parasitic' energy and associated carbon cost of this pump is significant. Other systems use lower-power pumps, and may even use a small photovoltaic array to power the pump, eliminating parasitic consumption altogether.

It is clear that for some systems (those with separate preheat tanks) the heat obtained from the system can be measured at the output of the collector, or at the output of the preheat tank.

Whilst the latter approach probably gives a better indication of the actual useful contribution, it has the disadvantage that comparable measurements cannot be taken on systems without a preheat tank. Furthermore, the dynamics associated with the preheat tank greatly complicate the analysis of system output in terms of incident solar radiation. It is therefore suggested that measurement of the actual collector output is undertaken in all cases. Since any preheat tank is likely to be very highly insulated any subsequent tank losses will, in practice, be very small.

For some systems, measurement of heat output at the collector opens up the possibility of specifying a controller which measures the flow in the collector loop, and uses this information together with flow and return temperatures to calculate system heat output. This approach may result in a small cost saving when compared to an independent heat meter.

Monitoring energy and carbon performance in new homes

Table 2: Monitoring requirements: solar water heating

Performance indicator(s)	Key drivers	Measurements
Contribution to water heating requirement	Array plane solar radiation	System heat output
Parasitic electricity consumption		System electricity consumption Array plane solar

4.3 Photovoltaics (PV)

The key output from a photovoltaic system is electricity, normally fed to the grid. Whilst consumption within the dwelling exceeds the amount being generated, a part of that consumption is offset. If generation exceeds consumption, power will be exported to other users on the grid. This will not be registered by a normal electricity meter (which does not respond when 'run backwards'). Thus in table 3 below, a dwelling export meter has been included as additional instrumentation.

Where dwellings feature different technologies (most notably solar water heating and photovoltaics) it may be possible to share sensors between them, giving cost reductions.



Figure 6: Photovoltaics

Table 3: Monitoring requirements: photovoltaics

Performance indicator(s)	Key drivers	Measurements
System electrical energy output	Array plane solar radiation	System electrical output
		Dwelling electricity export
		Array plane solar

4.4 Wind turbines

The key output of a wind turbine is electrical energy, again normally fed to the grid. The key input driving the system is wind speed, although in an urban environment surrounding obstructions may make wind direction a key variable as well. As with photovoltaics there may be periods when the dwelling is a net electricity exporter, and an electricity meter to register this has been included.

The monitoring of the electrical output of a wind turbine is complicated slightly by the fact that some turbine inverters consume a significant amount of power when the wind speed is below the cut-in value. To obtain a comprehensive picture of performance it is necessary to measure both energy exported to the grid, and also energy consumed under zero output conditions.



Figure 6: Wind turbine

Monitoring energy and carbon performance in new homes

Table 4: Monitoring requirements: wind turbine

Performance indicator(s)	Key drivers	Measurements
System electrical energy output	Wind speed and direction	System electrical input/output Dwelling electricity export Local wind speed and direction

A further complication arises from the fact that the output of a wind turbine varies very sharply with wind speed (it is generally proportional to the speed cubed). Thus a turbine which cuts in at 3ms^{-1} and cuts out at 12ms^{-1} will have a range of power outputs of 64:1.

These two considerations mean that the choice of electricity meter is more critical than for the other technologies considered here. Suitable instruments exist, but the more exacting requirements inevitably mean that there is an associated price premium.

4.5 Heat pumps

The output of a heat pump will normally be via a water loop, either to space heating or to a hot water storage tank. This provides a convenient point at which a heat meter can be inserted to measure system output. The key drivers are the electricity consumed by the system, and also the temperature from which the heat pump is extracting energy. Depending on the design of the system, this may be external air temperature (which is already measured for the purposes of building fabric appraisal), an air temperature within the building (for example in a conservatory), or a ground temperature.

In some cases a heat pump may be reversed, and used for cooling a building during the summer. In this case bi-directional heat metering is required, either from a specialist heat meter or from two conventional meters connected 'back to back'. This mode of operation is relatively uncommon in single dwelling installations, but it may be encountered if larger installations are eventually included in the programme.



Figure 7: Ground loop and trench for ground source heat pump

Table 5: Monitoring requirements: heat pump

Performance indicator(s)	Key drivers	Measurements
Contribution to heating requirements Ground or appropriate air temperature	Electrical input	System heat output System electricity consumption Ground or appropriate air temperature

Table 6 outlines the resolutions and accuracies required of each measurement to ensure that useful analysis can be carried out even over short time intervals.

Monitoring energy and carbon performance in new homes

Table 6: Resolutions and accuracies

Measurement	Resolution	Accuracy
Gas used as heating fuel	0.001m ³	± 2%
Dwelling electricity consumption/export	1 Wh	± 2%
Water consumption	1 litre	± 2%
Internal temperatures	0.05°C	± 0.25°C
Humidity	1%	± 3%
External temperature	0.05°C	± 0.5 °C
Solar water system heat output	1 Wh	± 3%
Solar radiation	1 W/m ²	± 5%
PV system electrical output	1 Wh	± 2%
Wind turbine electrical input/output	0.1 Wh	± 2%
Wind speed	0.1ms ⁻¹	± 5%
Wind direction	1°	± 5°
Heat pump heat output	10 Wh	± 2%
Ground temperature	0.05°C	± 0.25°C

5. Climate data

In section 4 a number of the quantities listed for measurement can be considered to be 'climate' variables. Examples are external air temperature, ground temperature, solar radiation and wind. For a single property monitored in isolation, these quantities can be recorded using the same data acquisition system that records data from inside the dwelling.

When several properties are monitored in a cluster, the fact that they share the same climate allows a significant saving in resources, since only one set of climate data is required for the whole site. Table 7 summarises the measurements which can be transferred from the dwellings to a site weather station.

A further advantage of the approach of using a central climate monitoring station is that since it contains

only one data logger, it can be easily equipped with a GSM modem for regular remote collection of data. In this way the risk of losing significant amounts of this key information is greatly reduced.



Figure 8: External temperature reader

Table 7: Climate measurement

Technology	Climate variable(s)
Dwelling fabric	External temperature
Solar water heating	Solar radiation in array plane
Photovoltaics	Solar radiation in array plane
Wind turbine	Wind speed and direction (provided weather station has representative exposure)
Heat pump	Ground temperature at appropriate level or external temperature

Monitoring energy and carbon performance in new homes

6. Presentation of results

Monitoring projects carried out over the last 30 years have produced vast quantities of data from dwellings. However, it has seldom been possible to make comparisons of the relative merits of different building techniques or renewable systems, mainly because results were never presented in a single, consistent format.

To achieve the objectives outlined in the introduction to this document it will be necessary to tabulate:

- Actual measured consumptions and inferred emissions.
- An 'output versus input' plot for each renewable technology incorporated in the building. This has different interpretations for different technologies, but it will generally provide a measure of the 'efficiency' of the system. This can then be related to the conditions under which the system is operating. For example, the coefficient of performance (CoP) for a ground source heat pump might be expressed as a function of source and sink temperatures.
- The consumptions and emissions normalised to some climate standard. The most appropriate choice of climate standard is probably that which underlies the SAP calculation. In this way normalised consumptions can be directly compared with SAP expectations derived at the design/compliance stage.

As described in section 2.1, some of these outputs will not be available from simplified monitoring where data is recorded at relatively long time intervals. The summaries below assume that the full level of monitoring is being carried out, with data gathered at five minute intervals.

The data which will be collected will contain a huge amount of additional information, and much further analysis will probably be carried out. It is stressed that these requirements form a bare minimum specification for data analysis and presentation.

The following information must be presented for these different elements:

Dwelling fabric

- Details of measured annual gas, electricity and water consumption.
- Plot of energy input from gas and electricity against the difference between internal and external temperatures.
- Normalised gas, electricity and water consumptions and associated emissions.

Solar water heating

- Gross heat output to hot water system and carbon equivalent.
- Parasitic electrical energy consumption and carbon equivalent.
- Plot of daily heat output against array plane solar radiation (system efficiency plot).
- System output normalised to radiation levels employed in SAP calculation.

Photovoltaics

- System electrical output and carbon equivalent.
- Plot of daily electrical output against array plane solar radiation (system efficiency plot).
- System output normalised to radiation levels employed in SAP calculation.

Wind turbine

- System electrical output and carbon equivalent.
- Parasitic electrical energy consumption and carbon equivalent.
- Plot of electrical output against wind speed (turbine power curve).
- System output normalised to wind level and obstructions assumed in SAP calculation.

Heat pump

- System heat output and corresponding electrical energy consumption.
- Plot of daily heat output against electrical energy consumption (system CoP plot).

Monitoring energy and carbon performance in new homes

7. Co-operation from developers

Co-operation from developers will be needed for both short and long-term performance monitoring.

For short-term testing, they will need to make completed dwellings available for:

- One-day tests of airtightness. This is a requirement for building regulations approval, and for the first (pre-occupancy) test does not therefore represent additional effort. For the subsequent (post-occupancy) test it will be necessary to ensure that the building owner-occupier is aware that access will be required.
- Tests on mechanical ventilation and heat recovery systems. These tests will again typically be completed within one day.
- Co-heating tests of building fabric. These will need a period of approximately two weeks after the building is completed, but before it is occupied.

For long-term testing, developers will need to:

- Liaise with utility companies to ensure that gas, electricity and water meters have pulsed outputs suitable for connection to the data acquisition system.
- Provide an external, lockable cabinet to house the data acquisition system.
- Provide a mains power supply to the data acquisition system. The fact that data collection will consume a small amount of power (probably 10 to 30 Watts depending on the selection of technologies installed) will need to be made clear to the occupier. The annual running cost should amount to no more than £30 per year and it will almost certainly be necessary to recompense the householder for this.
- Provide low-voltage cabling to the data acquisition system at the electrical first fix stage.

8. Indication of monitoring costs

Table 8 summarises the approximate costs of the equipment required to monitor a single dwelling which may feature any of the renewable technologies discussed above.

Further costs fall into two categories: installation and data collection and analysis.

The cost of installation depends very much on the building configuration, but installation in new buildings is always likely to be much simpler than trying to fit the necessary wiring and instrumentation into existing stock. Installers of renewable energy systems are now becoming increasingly familiar with the need for monitoring equipment and most PV systems, for example, are already equipped with a miniature electricity meter which would be suitable for connection to the type of monitoring system considered here. In the case of other systems, the installation of monitoring equipment at the time the system itself is installed represents only a small additional cost.

The remaining installation cost falls into two parts:

- Cables will be required from each sensing position to the data acquisition system. These are low voltage cables and can conveniently be installed at the electrical first fix, with minimum additional cost. Asking the installer to label the cables is often fruitless, and systems now exist which allow the person who subsequently connects up quickly to identify which cable is which.
- The sensors will need to be connected to the cables, those cables will in turn need to be connected to the chosen data acquisition system and the monitoring system needs to be commissioned. Past experience suggests that this work is best done by operatives experienced in data acquisition, rather than entrusted to site electricians.

As discussed in section 2 there are a number of ways in which data can be collected. The staff effort required to carry out this data collection will depend on the geographical distribution of the dwellings, and the frequency at which data is collected. If a cluster of houses contained up to 25 dwellings and staff to carry out the data collection were available locally then it is likely that each data collection visit could be completed within one day. Initially, this might be done every month, but as confidence in the data collection equipment grows the intervals between collections could be significantly increased.

Monitoring energy and carbon performance in new homes

Table 8: Monitoring costs

Technology	Equipment required	Approximate equipment cost	See note(s)	Option cost
Dwelling fabric	Data acquisition system	£1,200	1	£1,530
	Gas meter	Provided by utility company	–	
	Electricity meter			
	Water meter			
	Internal temperature sensors	£150	–	
	External temperature sensor	£100	2	
	Internal humidity sensor	£80	3	
Solar water heating	Heat meter	£400	–	£650
	Electricity meter	£50	–	
	Array plane solarimeter	£200	2	
Photovoltaics	Electricity meter	£50	–	£300
	Dwelling electricity export meter	£50	–	
	Array plane solarimeter	£200	2, 4	
Wind turbine	Import/export electricity meter	£250	–	£600
	Dwelling electricity export meter	£50	4	
	Wind speed and direction	£300	2	
Heat pump	Heat meter	£400	–	£550
	Electricity meter	£50	–	
	Ground or air temperature sensor	£100	2, 4	

Notes:

1. It is assumed that the data acquisition system chosen will be capable of recording data from as many technologies as are likely to be installed in any one dwelling, or that an upgrade to include additional inputs will be available at minimal cost. The cost of a GSM modem (for remote data downloads) and accessories has been included in the total system price.
2. As discussed in section 5, certain (climate) sensors can be shared between multiple dwellings on one site, giving a cost saving when several dwellings are clustered together. However, it should be noted that this option may require an additional data acquisition system.
3. A small cost saving may be made if internal humidity and one internal temperature are measured in the same location.
4. As discussed in section 4, some sensors may be shared between different technologies in a single dwelling. This will result in further cost savings.

Monitoring energy and carbon performance in new homes

9. The impact of number of dwellings monitored

So far, this document has considered the process of monitoring the performance of a single dwelling. Whilst that is obviously of interest to the occupier, in a broader context it may also be desirable to draw some conclusions about the performance of the whole population of dwellings of that type.

It is well known that the behaviour of the occupants can create significant variations in the energy consumption of identical dwellings. To get a picture of the performance of the population as a whole, it is therefore necessary to measure the performance of more than one dwelling of each type. As more dwellings are monitored, the uncertainty in the estimate of the mean consumption of the whole population decreases, but only as the square root of the number monitored. Subject to certain assumptions about the randomness of the sample, and statistical independence within the population, the standard deviation of the estimate of the population mean is given by:

$$\frac{s}{\sqrt{n}}$$

where:

n is the number of properties measured, and
 s is the standard deviation within the population.

In practice, the standard deviation within the population is not known until some measurements have been made and it can be estimated. Previous studies for the Energy Saving Trust, in which the impact of installing insulation measures was assessed by taking measurements very similar to those outlined in this document, made some broad assumptions about this and concluded that an appropriate sample size was about 100 (for each measure investigated).

Subsequent data analysis indicated that this size of sample did indeed produce useful results, indicating that the assumptions were appropriate. If the standard deviation of consumption in houses of the same type is indeed $\pm 50\%$ then a sample of 100 houses of each type considered allows the mean to

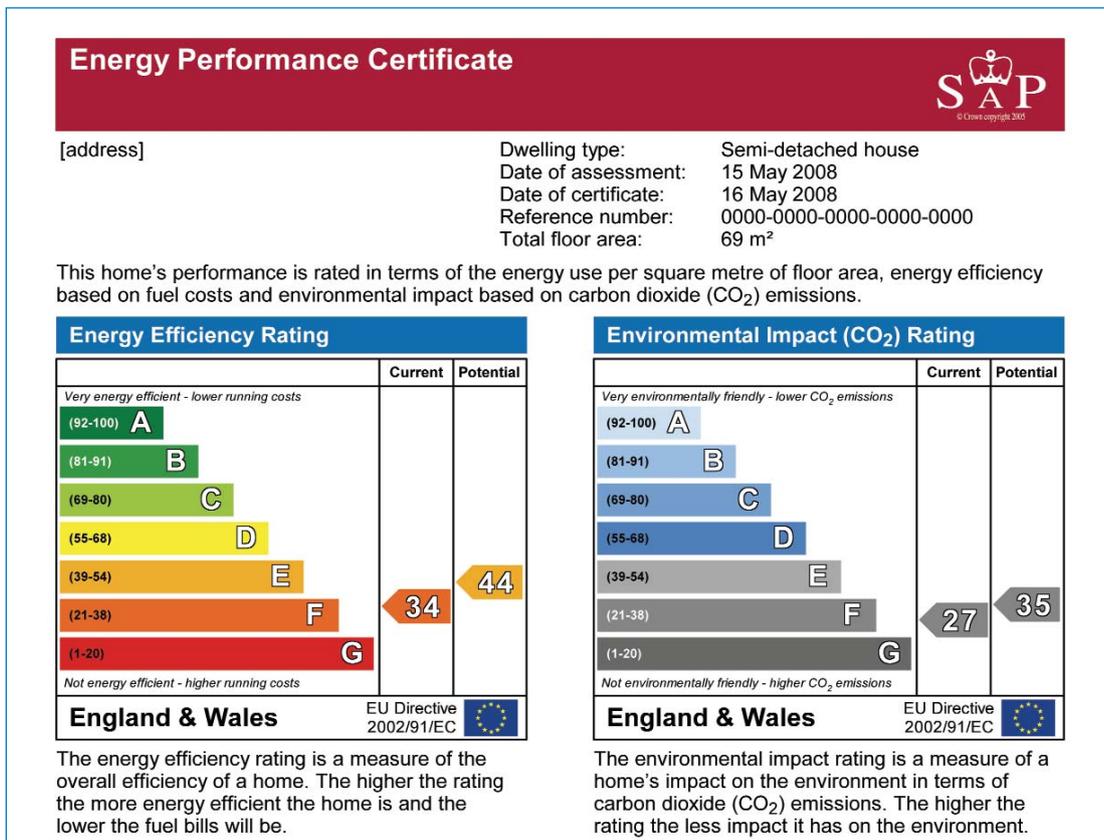


Figure 9: Extract from sample Energy Performance Certificate

Monitoring energy and carbon performance in new homes

be identified to within $\pm 5\%$. Given the magnitude of the savings anticipated by the Code for Sustainable Homes (25% for Code level 3 and progressively higher for subsequent levels) it seems likely that a sample of this size will allow the savings to be quantified to a useful level of accuracy.

In situations where a sample of 100 homes will not be available, useful information can still be gathered about the performance of single dwellings, but the degree of certainty to which the performance of the population as a whole can be estimated deteriorates. Figure 10 below shows how this uncertainty increases as the sample size is reduced.

Figure 10 indicates that due to the presence of the square root, the uncertainty increases only gently at first. This means that a useful indication of the performance of the population as a whole could be obtained with a samples as small as 25 for the test and control groups. It also indicates that the sample

size has to fall to four before the uncertainty in the estimate of the population mean becomes equal to the 25% reduction in consumption expected from a Code level 3 house. The interpretation of this is that with samples as small as this it is quite possible that the Code level 3 sample would show higher carbon emissions than the control group, even if the Code level 3 measures were actually achieving the desired 25% reduction across the whole sample. This is clearly a very undesirable outcome.

It must be stressed that the discussion above is based on the premise that the variation in carbon performance within each population is 50%. Whilst this value has seemed roughly appropriate in earlier studies, a firm indication of the actual value will only be obtained once some monitoring has actually been carried out.

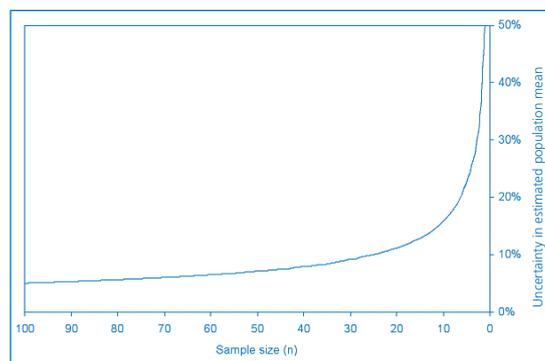


Figure 10: Uncertainty of information in relation to sample size

Monitoring energy and carbon performance in new homes

10. Further information

The Energy Saving Trust provides free technical guidance and solutions to help UK housing professionals design, build and refurbish to high levels of energy efficiency. These cover all aspects of energy efficiency in domestic new build and renovation. They are made available through the provision of training seminars, downloadable guides, online tools and a dedicated helpline.

A complete list of guidance categorised by subject area can be found in our publications index 'Energy efficiency is best practice' (CE279). To download this, and to browse all available Energy Saving Trust publications, please visit www.energysavingtrust.org.uk/housing

The following publications and resources may be of particular interest:

General information

Energy efficiency frequently asked questions (CE126)

Post-construction testing: a professional's guide to testing housing for energy efficiency (CE128/GIR64)

For a variety of shorter introductory guides, visit www.energysavingtrust.org.uk/resources

Code for Sustainable Homes

Energy Efficiency and the Code for Sustainable Homes – Level 3 (CE290)

Energy Efficiency and the Code for Sustainable Homes – Level 4 (CE291)

Energy Efficiency and the Code for Sustainable Homes – Level 5 & 6 (CE292)

Insulation

Insulation materials chart – thermal properties and environmental ratings (CE71)

Windows

Windows for new and existing housing (CE66)

To view a list of BFRC rated windows, please visit www.bfrc.org

To view a list of the most efficient windows currently available, please visit www.passivhaus.org.uk

Airtightness and efficient ventilation

Improving airtightness in dwellings (CE137)

Achieving airtightness in new dwellings: case studies (CE248)

Energy efficient ventilation in housing (GPG268)

Renewables

Renewable energy sources for homes in urban environments (CE69)

Domestic ground source heat pumps (CE82)

Solar water heating systems (CE131)

To obtain these publications or for more information, call 0845 120 7799, email bestpractice@est.org.uk or visit www.energysavingtrust.org.uk/housing



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