Green gauges

Lessons learnt from installing and using metering and monitoring systems in low carbon buildings
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Metering and monitoring installations are one of the most cost-effective measures you can use to deliver a low carbon building.
Sharing our experience: About this booklet

*Green gauges* is part of the ‘Sharing our experience’ series. These booklets provide advice and tips to help you plan, build and manage cost-effective low carbon buildings that really work to save you money and carbon.

The insights are based on real data from 28 case studies from the Department of Energy and Climate Change’s Low Carbon Buildings Programme and our work on refurbishments. The projects cover many sectors including retail, education, offices and mixed use residential buildings.

Further information
To find out how we can help with your low carbon building project, contact us on 0800 085 2005 or visit [www.carbontrust.co.uk/buildings](http://www.carbontrust.co.uk/buildings)
What are metering and monitoring systems?

Energy metering and monitoring systems are a relatively cheap combination of hardware and software that provide vital feedback on building performance. They are essential for any building that aspires to be cost effective to run and low carbon.

Smart meters automatically collect and send half-hourly energy data to energy suppliers. They are now typically installed as the main meters in most new commercial buildings.

Sub-meters provide the next level of detail, allowing you to break down energy use (e.g. for lighting, heating or cooling). They often also provide profiles using data collected every half hour, which can be used to identify unusual patterns of use, or other anomalies that may indicate poor controls or faults. These meters are required by Part L of the Building Regulations.

When used together these meters can form part of an automated monitoring and targeting system that can be used by facility and energy managers to track and reduce energy use, ensuring that a low carbon building lives up to its design potential and saves money.

Key components

Systems are made up of:

- Separate electronic meters that measure electricity, heat, gas and water use and transmit half hourly data, also often storing that information.
- A data collection system that gathers data sent from the meters in a database on a computer or remote server. The data is sent via a communication link (e.g. hard wire, radio, ethernet or mobile phone network).
- Energy reporting software, either on-site or on a web server, which can process and analyse energy data, often automatically reporting exceptional use. This software is becoming continually more sophisticated and powerful and may also connect to a bigger enterprise level database and carbon management software.
- Somebody to look at the data and take action. Meters need to be read and their data collected, analysed and used, otherwise they’re useless. So this is the most important part.
Electricity submeters

The majority of meters installed in our case study projects were electricity submeters, which are relatively inexpensive to purchase and install (less than £300). Devices such as variable speed drives are now often able to provide energy data themselves, so items like air handling units can be metered at virtually no cost.

Heat submeters

Heat or energy submeters were installed in all case study projects to measure heat energy produced by boilers or heat pumps. They are slightly more expensive than electricity meters to purchase and install (£500-£1,000 depending on size).

A heat meter is a device combining:

- a water flow meter
- flow and return temperature sensors
- an integrator box that calculates the heat or cooling energy used by multiplying the temperature difference by the amount of water.
Data collection systems and software

Meters can be read manually or remotely. All the commercial case study projects had automatic data collection systems installed, using a database with software on a local or remote server. There is no standard for these systems and the software can provide simple reports through to detailed analysis. The savings on staff time are much greater than the cost of installing the systems.

For new buildings that are larger than 1,000m² you will need to install an automatic data collection system under current building regulations. These systems are also eligible for enhanced capital allowances, which reduce the up-front cost.

Figure 1 Metering and monitoring system components and how they are connected
Metering in practice

The number of meters installed in each of the projects studied ranged from 50 to 150. All of the projects had some form of remote meter reading and data collection system.

Each metering and monitoring system is designed especially for the building in which it is used, so the size and cost of the system installed within a case study project reflects the size and type of building.

Figure 2 The statistics for three buildings in our case studies

<table>
<thead>
<tr>
<th>Edgehill University</th>
<th>Dandridge’s Mill</th>
<th>Swansea LC</th>
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<tbody>
<tr>
<td>7,000m² Faculty of Heath building</td>
<td>850m² conversion into 4 dwellings</td>
<td>12,000m² leisure centre</td>
</tr>
<tr>
<td>15 electricity sub meters</td>
<td>8 electricity sub meters</td>
<td>42 electricity sub meters</td>
</tr>
<tr>
<td>6 heat sub meters</td>
<td>8 heat sub meters</td>
<td>21 heat sub meters</td>
</tr>
<tr>
<td>3 gas meters</td>
<td>4 gas meters</td>
<td>3 gas meters</td>
</tr>
<tr>
<td>Data collected via BMS</td>
<td>Data collected via internet via dedicated data collection system</td>
<td>Data collected via BMS</td>
</tr>
</tbody>
</table>
“The right metering and monitoring system will more than pay for itself by allowing you to see whether your low carbon building is saving money as you intended and not wasting energy.”
**Why meter and monitor?**

Energy metering and monitoring systems are a relatively cheap combination of hardware and software that provide vital feedback on building performance. They are essential for any building that aspires to be cost effective to run and low carbon.

**Motivations**

Our case studies gave the following reasons for installing their monitoring and metering systems:

- to reduce avoidable energy waste and save money
- to comply with building regulations\(^1\) and BREEAM requirements
- to track and optimise the performance of the low and zero carbon technologies installed within the buildings
- to bill tenants
- to track the overall energy performance of the buildings and compare between buildings in their portfolio
- to detect faults.


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**Figure 3 Costs and benefits of best practice metering and monitoring**

![Costs and Benefits Chart]

- **Utility meters**
- **Submeters**
- **Unnecessary meters**
- **Added components**
- **Energy savings**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (£)</th>
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<tbody>
<tr>
<td>Metering cost in a typical small project</td>
<td>$20,000</td>
</tr>
<tr>
<td>Remove Unnecessary Meters</td>
<td>$10,000</td>
</tr>
<tr>
<td>Add extra meters, AM&amp;T system, Labels, Commissioning &amp; Training</td>
<td>$20,000</td>
</tr>
<tr>
<td>Metering cost in a best practice project</td>
<td>$60,000</td>
</tr>
<tr>
<td>Energy savings from monitoring best practice project over 10 years</td>
<td>$20,000</td>
</tr>
</tbody>
</table>
Another more recent incentive is the need created by the Feed-in Tariff and the Renewable Heat Initiative to monitor the output from renewable energy systems. The CRC has also provided an additional drive to meter and track energy use.

**Save money by cutting waste**

A good metering strategy also allows you to recognise when systems are not operating as intended and to take action to resolve any issues quickly and cost-effectively.

Energy submetering can help to identify energy that is being wasted. Our case studies showed that sub-metering can be particularly useful to identify where low or zero carbon technologies are under-performing or where several technologies are conflicting.

We helped St Edmundsbury Borough Council use energy sub-metering to identify that, instead of the heat load in their new building being met by the ground source heat pumps as intended, it was being met by the back-up gas boilers. The carbon penalty was over 15,000 kg of CO$_2$ per annum. Heat metering on individual heat pumps could have improved the speed of diagnosis further.

**Figure 4** An example of a half-hourly profile from metering data. It’s likely that this school could reduce the high energy use at night and at the weekends, as systems seem to be running when the building isn’t being used.
**Fast fault detection and diagnosis**

Most of the case studies were made aware of faults through metering data, which they wouldn’t otherwise have known about.

At Pembrokeshire College metering on the solar hot water system identified a pump failure during the first six months that would probably have remained undetected during the life of the system. On another project, building managers didn’t monitor solar hot water output against the design prediction and missed a leak for three months over summer when the system could have been saving carbon and money.

**Cost and carbon effectiveness**

Metering and monitoring installations are one of the most cost-effective measures you can use to deliver a low carbon building.

Experience from previous field trials conducted by the Carbon Trust showed that when properly used, smart metering could cut on-site carbon emissions by 5%–12%.

This case is strengthened by evidence from our case study projects suggesting that a good submetering and monitoring system can be even more cost-effective with the savings it identifies in the first two years of occupation.

In one large retail refurbishment case study, the sub-meters, combined with effective monitoring, identified potential savings that equalled the cost of the meters and monitoring system installed after only two years.

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**Lessons learned**

- Metering and monitoring reduces energy and carbon waste and produces cost savings.
- Good submetering is essential to ensure a building is low carbon.
- Heating systems with multiple sources need extensive metering to optimise performance as well as someone who can act on the information.
- Metering and monitoring enables faults to be detected that may not be detected by other means.
- Good metering allows occupants to understand low carbon building performance better.

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2 Advanced metering for SMEs (CTC713), Carbon Trust.
Planning a metering and monitoring system

If your metering and monitoring system is to succeed, you will need to be actively involved from an early stage. You’ll also need to develop a metering strategy that sets out your aims and addresses the needs of users.

Client engagement
As a client, you’ll need to be actively involved in refining the metering and monitoring requirements of your client brief. Don’t leave it to a design team, as you need to understand and define with them the priorities of your organisation and how the building will be run. This is important information for a metering strategy.

Champion
Projects where a metering champion has been appointed have had more successful metering and monitoring outcomes.

At Edgehill University a member of the facilities management team who was to use the energy data was involved and acted as metering champion throughout the project stages, from planning to commissioning. This was identified as a key factor in the success of the system.

Focus on outputs
It is important to state what outputs you need the metering and monitoring system to deliver. Many teams implemented the requirements of building regulations and BREEAM, but in many cases this resulted in some meters being installed that did not provide useful information, or monitoring systems that had too limited a capability which nobody used.

The most successful outcomes were often in projects where metering is used for billing tenants and where the client had a real stake in ensuring that the metering and monitoring system was well designed and commissioned successfully.

At the Greenhouse project in Leeds, where a 1930s building has been converted into 166 eco-homes, the metering system provides billing data directly to occupants via an internal TV channel.
Identify end users of the system

Consider who will collect the data and how it will be used to produce reports:

- If you are looking to produce bills for tenants, this will influence not only the reporting format but also the type of meter you will need (requires OFGEM-approved meters).
- The information required depends on who is going to be reviewing and using it. For example, a facilities manager or engineer will need different information to a member of the finance team.
- A standalone data collection system is better if the end user is not going to be able to readily access data on the building management system.

These factors will influence the selection of the meters, design of the communications system and the functionality required from monitoring software.

Displaying and reporting energy data

Our case studies told us that when meters are displayed as numbers in a table on the BMS, it is difficult to interpret trends or detect exceptions. This meant much of the valuable information that can be extracted from the monitoring system was not used.

Consider the specification of reporting software. This software can generate reports tailored as graphs for you, which are easy to read and understand. Alternatively, you may want to use an external energy bureau service, especially if you have multiple sites, as they can be a cost-effective way of handling and responding to large volumes of energy data and comparing across sites.

At Edgehill University’s Learning and Resource building, energy data from the building is displayed on an “energy wall”, which has proved very popular with both students and staff. The display changes from green to red when the energy consumption is above the planned level, prompting staff to take action.

Lessons learned

- The client must be involved in defining the purpose of the metering and monitoring system.
- Appoint a metering champion to make sure that a useful and fully functioning system is delivered.
- Don’t focus too narrowly on regulatory compliance – you may then install more meters than you need.
- Focus on the output you need from the system and consult with potential end users, such as facility managers.
Getting a metering strategy to work

To get a metering and monitoring system that works from day one, you’ll need designers and installers to develop your metering strategy and focus on potential weak points, including heat meters, renewables and data collection systems.

**Metering strategy**

Guidance on preparing a metering strategy is provided in CIBSE TM39. This can be used to meet legislative requirements as set out in Building Regulations ADL2.

Several of our case studies did not produce a strategy. This led to poor design, installation and commissioning. The table on page 16 gives our findings and tips for key end uses.

**How many is too many meters?**

A question that is often asked is “At what point does it become not cost effective to meter a small consumption?” Unless the meter is being installed for a large specialist load, e.g. a large server room or catering load, then each meter should measure 5%-10% of total load. Renewables should always be metered separately.

At one site, 20 small electrical distribution boards were metered. These meters provided data on small loads that the site didn’t find useful; consequently the meters were rarely read. The £8,000 cost of these meters could have been used on other energy saving measures.

**Renewable energy technologies**

Renewable technologies need to be properly metered to make sure they are performing as intended.

Where renewables interact and may compete with conventional energy sources, you will need separate metering for each energy source, e.g. if the heat demand for your building is supplied by heat pumps and gas boilers, you’ll need to meter the heat output of both systems.

If you have a limited metering budget, it will usually be better to prioritise the metering of renewables, and sacrifice the metering of small conventional energy loads such as lighting.

The table on page 16 gives our findings and some tips on metering different types of renewable energy technologies.
Top tips for successful heat metering

- The meter must be sized to operate within its design flow range. It is important not to oversize as the meter may be inaccurate or not pick up low loads.
- Ensure that the meter is to be installed where there is a smooth flow into it, i.e. it is installed at the required number of pipe diameters away from bends or constrictions.
- It is important that the meter operates with as high a differential temperature between flow to the load and return as possible. This is an important factor to consider when measuring the output of chillers as the temperature difference between flow and return is often very low.
- Battery powered heat meters are not recommended as they are not maintained.
- Proper commissioning and handover are critical – see Ensuring best performance.

Heat meters

Our experience with the case studies suggests that heat and energy meters can be problematic and need to be designed and installed particularly carefully.

Collecting data from meters for monitoring

The two main choices made in our case study projects were:

- to install meters and use the BMS to collect the data
- to install meters and a separate data collection system.

Metering and building management systems (BMS)

This solution was used in the majority of projects where there was going to be a BMS installed on site. A single system to both control energy use and gather energy data is attractive as it can save on wiring, installation and hardware costs.

The disadvantage is that a BMS is not designed with metering and monitoring in mind:

- a BMS is often not designed to store and analyse large quantities of historic data
- a BMS is often not designed to produce monitoring reports, although they can be adapted to do so.

Many projects using a BMS to collect, store and display data have also suffered from problems and delays during the commissioning of these systems, as well as long-lasting operational problems that meant energy data could not be used.
**Separate end-to-end metering system**

The specification and installation of a specialist metering and monitoring system may cost more, but offers advantages over the use of a BMS. These systems are provided by specialist suppliers and are independent of the BMS.

The systems offer flexible and easy to use monitoring, analysis and reporting packages. The metering specialist will also have the expertise to ensure that meters and communications systems are designed and commissioned correctly to minimise failures.

These systems also often integrate better with energy bureau services providing remote monitoring.

**Lessons learned**

- Don’t specify too many meters. Make sure you set out how they will be used in the metering strategy.
- When producing a metering strategy, be sure to include full metering of renewable energy technologies.
- Heat meters require careful specification and commissioning.
- Specialist metering and data collection systems procured on a turnkey contract offer many advantages over integration of metering with a BMS.
**Figure 5 Metering and monitoring of renewables**

<table>
<thead>
<tr>
<th>System</th>
<th>What meters can tell you</th>
<th>LCBP experience</th>
<th>Recommended metering</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground source heat pumps</strong></td>
<td>Efficiency of heat pump</td>
<td>70% of ground source heat pump sites failed to adequately meter their systems</td>
<td>As a minimum, meter the heat output and the electrical supply to each heat pump</td>
</tr>
<tr>
<td><strong>Small wind</strong></td>
<td>Is it working? Metering each turbine as well as wind speed and turbulence will help you monitor effectiveness and claim feed-in tariff. Refer to our small wind guide for details</td>
<td>Metering and monitoring provided by turbine supplier ensured 100% success</td>
<td>Meter the electrical output from the turbine and local wind speed</td>
</tr>
<tr>
<td><strong>Solar hot water</strong></td>
<td>Is it working? Also the lack of submetering makes it very difficult to work out the efficiency of other heat sources</td>
<td>Low flow rates made metering difficult and required accurate specification. Of the sites, 20% considered loads too small to merit metering (less than 5kW heat), making it difficult to assess whether it was working</td>
<td>Meter the heat output from the panel</td>
</tr>
<tr>
<td><strong>Photovoltaics</strong></td>
<td>Is it working? It is important to monitor the output of the panels to claim support under the feed-in tariff and to spot whether an inverter has failed</td>
<td>Metering and monitoring provided by PV suppliers was generally successful</td>
<td>Meter the electrical output from the panels</td>
</tr>
<tr>
<td><strong>Biomass</strong></td>
<td>Calculation of boiler efficiency and distribution losses – heat out of boiler room and heat supplied to each area</td>
<td>80% of sites managed straightforward solutions</td>
<td>Meter the heat output from the biomass boiler</td>
</tr>
<tr>
<td>System</td>
<td>What meters can tell you</td>
<td>LCBP experience</td>
<td>Recommended metering</td>
</tr>
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<td>-----------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Gas boilers</td>
<td>Combustion efficiency of large boilers. Calculation of boiler efficiency and distribution losses – heat out of boiler room and heat supplied to each area</td>
<td>Most sites monitored the gas input into the boilers</td>
<td>If boilers are large (&gt; 500kW) then meter the heat output and gas supply. For smaller boilers monitor the gas supply, unless it is combined with other heat sources (e.g. GSHP)</td>
</tr>
<tr>
<td>Chillers</td>
<td>Calculation of chiller efficiency</td>
<td>Supplier provided solutions ensured 100% successful metering and monitoring</td>
<td>Meter the electrical supply to chillers. On chillers over 250kW or where there are additional cooling sources (e.g. GSHP) consider installing additional heat meters for each one</td>
</tr>
<tr>
<td>Lighting and small power</td>
<td>The amount of electricity consumed by lighting and by small power loads</td>
<td>Trying to meter lighting and small power all too often resulted in a large number of meters that were not read</td>
<td>Lighting and small power demand can be easily estimated. Don’t submeter them unless you know how you are going to use them</td>
</tr>
<tr>
<td>Air handling units</td>
<td>Fans typically represent a significant load</td>
<td>This proved to be relatively easy to do with modern variable speed drives (VSD)</td>
<td>Meter any fan motor over 5kW using VSD</td>
</tr>
<tr>
<td>Domestic hot water</td>
<td>Calculation of boiler efficiency and distribution losses – heat out of boiler room and heat supplied to each area</td>
<td>80% of sites managed straightforward solutions</td>
<td>Meter the make-up water to the domestic hot water. Important to meter when supplied by heat pump</td>
</tr>
<tr>
<td>Pumps</td>
<td>Pumps typically represent a significant base load</td>
<td>80% of sites managed straightforward solutions</td>
<td>Meter the main plant room</td>
</tr>
<tr>
<td>IT</td>
<td>IT equipment typically represents a significant base load</td>
<td>80% of sites managed straightforward solutions</td>
<td>Meter the server room</td>
</tr>
<tr>
<td>Catering</td>
<td>Energy used for storage, cooking and dish washing</td>
<td>80% of sites managed straightforward solutions</td>
<td>Meter all services to kitchens</td>
</tr>
</tbody>
</table>

Figure 6 Metering and monitoring of building systems and end uses
Ensuring best performance

People often overlook the need to commission the metering and monitoring system and engage with the facilities management team. But these stages are vital if your system is going to identify savings.

Commissioning

As meters aren’t essential for getting a building to work, their proper commissioning can feel like a hassle in the rush to hand over the building, but it can pay big dividends later on.

Of our case study projects, 80% had protracted commissioning and calibration issues with meters and data collection systems. These issues had a lasting impact on the systems’ effectiveness and, in many cases, the overall energy use of the buildings.

Where a metering specialist and/or metering champion were available on the project, the outcome was usually better.

Top tips for commissioning

- Define the metering commissioning methodology in detail during design.
- Require the commissioning report to include meters and the metering system as a separate item.
- Actual meter readings and changes must match with the values and changes on the BMS or data collection system. This should be demonstrated at the commissioning stage and detailed on the meter commissioning sheet.
- Check that readings fall within the expected range.
- Check that the summation of meters correlates with main meters.
- Check that meters are located appropriately and can easily be read.
- Check the contractually specified equipment is actually installed.
- Ensure that meters are numbered, labelled and identified correctly and that this is consistent throughout the system.
Using the logbook

In a number of projects, meters were not adequately labelled or documented by the contractors. This resulted in frustration for the end user as it was not clear what the meters were measuring.

The building log book and handover documentation should contain the following as a minimum:

• metering strategy schematic
• schedule of meters with their locations, meter identification number, the load they are metering and expected daily use
• meter specifications and O&M data sheets.

Case study
Stoke Local Service Centre

Stoke Local Service Centre quickly reaped the reward of installing submeters. When the heating was under performing, the sub-meters identified the two faulty heat pumps responsible and the problem was easily fixed. In contrast, another project without sub-meters faced a protracted and expensive process to pinpoint the source of the problems.
Using the metering and monitoring system

One important lesson from the case studies is that the end users of metering and monitoring systems need to be engaged and informed if the potential value from these systems is to be realised.

Make sure that the end user is trained to use the system. They should be made familiar with the metering installation and the locations of meters.

They should be asked to take readings from the meters and use the automatic monitoring system on a regular basis, especially during the initial few weeks and months after handover, so that faults can be identified quickly and a picture of the performance of the low carbon building can emerge quickly.

Maintenance

Periodically (preferably annually), all meters should be checked and calibrated to ensure they are operating correctly.

“If the operators are not properly trained, engaged, empowered or interested in the metering and monitoring system, the client’s investment is as good as wasted”

John Maxwell, Environ

Lessons learned

• Successful commissioning of metering and monitoring systems needs to be completed to ensure a low carbon building
• Labelling and documentation of meters is frequently overlooked, but essential for using meters
• End users must be trained to use the metering and monitoring system
• Systems should be used regularly from as soon as possible after completion
## Further information

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<th>CIBSE</th>
<th>The Carbon Trust</th>
<th>Energy Services and Technology Association</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TM39 Building Energy Metering</strong></td>
<td><strong>Advanced Metering Accelerator.</strong></td>
<td><strong><a href="http://www.estar.org.uk">www.estar.org.uk</a></strong></td>
</tr>
<tr>
<td>Sets out best practice in the design of energy metering and submetering.</td>
<td><a href="http://www.carbontrust.co.uk/emerging-technologies/current-focus-areas/pages/metering.aspx">www.carbontrust.co.uk/emerging-technologies/current-focus-areas/pages/metering.aspx</a></td>
<td>Association of metering and monitoring equipment and software suppliers.</td>
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<tr>
<td><strong>The Department of Communities and Local Government</strong></td>
<td><strong>The Carbon Trust</strong></td>
<td></td>
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<tr>
<td>Building regulations Part L2.</td>
<td><strong>Metering Technology Overview (CTV027)</strong></td>
<td></td>
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<td></td>
<td><strong>Automatic meter reading fact sheet (CTL083)</strong></td>
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The Carbon Trust is a not-for-profit company with the mission to accelerate the move to a low carbon economy. We provide specialist support to business and the public sector to help cut carbon emissions, save energy and commercialise low carbon technologies. By stimulating low carbon action we contribute to key UK goals of lower carbon emissions, the development of low carbon businesses, increased energy security and associated jobs.

We help to cut carbon emissions now by:
• providing specialist advice and finance to help organisations cut carbon
• setting standards for carbon reduction.

We reduce potential future carbon emissions by:
• opening markets for low carbon technologies
• leading industry collaborations to commercialise technologies
• investing in early-stage low carbon companies.

www.carbontrust.co.uk
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