# The scope for energy and $CO_2$ savings in the EU through the use of building automation technology

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*The scope for energy and $CO_2$ savings in the EU through the use of building automation technology.*

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## Glossary

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| Actuator | A motorised device that moves valves or dampers, normally in response to a signal from a controller/outstation. |
| AHU | air-handling unit |
| Analogue device | A device that provides an analogue signal (typically 0−10 V, 4−20 mA or a resistance) (e.g. damper position, lighting level) over its measurement range (e.g. 5−35 °C). |
| Analogue input | Input to *BMS* by an *analogue device* which provides a wide potential range of input values, depending on the magnitude of a specific variable, e.g. damper position, temperature, illuminance level, etc. |
| Analogue output | Output from *BMS* with a wide potential range of values, e.g. to dim lights or drive an *actuator* to a particular setting. |
| ASHRAE | American Society for Heating, Refrigeration and Air Conditioning Engineers |
| AV | audio-visual |
| BACnet | A communications protocol for building automation and control networks. |
| BACs | building automation and control systems |
| BAS | building automation systems; an alternative term to *BMS*. |
| BAT | building automation technology; includes any kind of automated controls from *thermostats* and time switches to more advanced *sensor* technology, etc. |
| BEMS | building energy management systems (Note: BEMS are really a sub-set of *BMS*, but not all BMS are set up to operate as BEMS even if they have the inherent capability, and thus the term BEMS is used in this report when referring to BMS set up to manage the building energy performance.) |
| BMS | building management systems; any computerised installations used to manage engineering systems in buildings (includes maintenance regimes, operation, occupant comfort and safety control, air-quality control, etc.). |
| Boiler sequence control | A control or switching of two or more heating boilers in order to achieve the desired heating capacity/temperature. This helps to maximise boiler efficiency. |
| BPIE | Building Performance Institute Europe |
| BRECSU | Building Research Energy Conservation Support Unit (in the UK) |
| BREEAM | Building Research Establishment Environmental Assessment Method; a voluntary measurement rating system for green buildings that was developed and is operated in the UK by the Building Research Establishment (some UK clients and public procurement bodies now require particular minimum levels of rating). |
| BSE | building services engineering |
| BSI | British Standards Institute |

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| Building services | Mechanical, electrical and control systems that form part of a building and support the activities of its occupants (includes heating, cooling, lighting, ventilation, water, waste, communication and safety systems). |
| CEN | Comité Européen de Normalisation (European Committee for Standardization) |
| CHP | combined heat and power |
| CIBSE | Chartered Institute of Building Services Engineers |
| Commissioning | The process of testing, checking or calibrating the function of any building services component, to advance it to a working order. |
| Compensation | The action of reducing the heating circuit flow temperature with increasing ambient temperature to reduce energy consumption and improve controllability of heat *emitters*. Additional temperature reset can be applied to take account of changes in space temperature, solar gain, etc. Boilers may also be directly compensated. Similar principles can be applied to chillers. |
| Compensator | A dedicated controller for *compensation*. |
| Continuous commissioning | An operational strategy that continues *Commissioning* beyond the original working settings of equipment and seeks to understand and optimise performance in use via an expert monitoring feedback and diagnostics process empowered with the authority to intervene to remedy significant failures when identified. |
| Controller/outstation | A device that controls *building services* components via inputs from *sensors* or remote signals and outputs to *actuators* and other equipment; the device can form part of *BMS* or stand alone. |
| Daylight sensing | Controls that monitor levels of daylight and switch electric lights on and off, or variable control (dimming) in response to the measured daylight level. |
| DCC | Demand Connection Code |
| DDC | direct digital control; the use of microprocessor-based controllers using digital electronics. |
| DETR | Department of the Environment, Transport and the Regions (former UK ministry) |
| DIN | Deutsches Institut für Normung (German Standards Organization) |
| EED | Energy Efficiency Directive |
| Emitter | A device that emits heat or cold, such as a radiator or fan coil. |
| EMOTR | energy, monitoring, optimising, targeting and reporting |
| EPBD | Energy Performance of Buildings Directive |
| ESCO | energy service company |
| ESD | Energy Services Directive |
| EU | European Union |
| eu.bac | European Building Automation Controls Association |
| European standard | A *standard* adopted by a European standardisation organisation. |
| GDP | gross domestic product |

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| HAN | home area network |
| HEMS | home energy management systems |
| HVAC | heating, ventilation and air conditioning |
| IBAS/IBMS | intelligent *BAS/BMS*; sometimes used to denote BMS that include functions in addition to *HVAC*, such as fire and security over the same network. |
| ICT | information and communication technology |
| IEA | International Energy Agency |
| IEC | International Electrotechnical Commission |
| Interlocking controls | Controls that prevent two or more systems, or functions, operating at the same time; an example of this is a *controller* that disables boiler operation following a fire alarm signal being activated or which prevents simultaneous heating and cooling. |
| IP | internet protocol |
| ISO | International Organization for Standardization |
| IT | information technology |
| LEED | Leadership in Energy and Environmental Design (LEED); a suite of rating systems developed by the US Green Building Council for the design, construction and operation of high performance green buildings, homes and neighbourhoods. |
| M&E | mechanical and electrical |
| National standard | A *standard* adopted by a national standardisation body. |
| Occupancy sensor | A device that detects whether people are present or absent from a space. |
| Optimiser | A dedicated *controller* for *optimum start/stop*. |
| Optimum start/stop | A control program that saves energy by operating *HVAC* systems for the minimum preheat period ('optimum start') in advance of the programmed occupancy time to meet the desired temperature for occupancy. Similar programs can be used for precooling of buildings. There may also be 'optimum stop', to switch systems off before the occupancy period ends, if conditions can be maintained without them. |
| PC | personal computer |
| PLC | powerline carrier |
| Sensor | A device that provides an analogue signal to a *controller/outstation*, typically temperature, humidity or flow. See also *actuator.* |
| Sequence control | A control that seeks to optimise the operation of multiple units of plant (e.g. a set of boilers or a set of chillers) to maximise their efficiency. |
| SMEs | small and medium-sized enterprises |
| Standard | A technical specification, adopted by a recognised standardisation body, for repeated or continuous application; compliance is not normally compulsory, unless the standard is referred to in legislation. |

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| Thermostat | A device that responds to temperature in a space, pipe, etc., to switch an item on or off. The control provided is usually less precise than using a *sensor*, *controller* or *actuator*, but thermostats can have advantages in terms of low cost and robustness (e.g. for safety cut-outs). They are low-cost devices and generally provide poor control compared with more sophisticated controls. |
| TRV | thermostatic radiator valve; a device that helps to control room temperature by altering the amount of hot water entering a heat *emitter*, in relation to the space temperature it detects. Traditionally these have been non-electric direct-acting, but some are now programmable, either locally or from a central point. |
| US(A) | United States (of America) |
| Variable speed control | Adjusts the speed of a fan, motor or pump to match its duty to the load or demand. Reducing speed will save energy. |
| VAV | variable air volume |
| VFC | variable-flow controller |
| VRF | variable refrigerant flow |
| Zones | Parts of a building that are controlled separately, owing to differing requirements, e.g. for the standards or operating times of *HVAC* or lighting. |

# EXECUTIVE SUMMARY

Until recently, building automated controls have not featured strongly in policy discussions regarding the potential to save energy in Europe's buildings; however, effective control of energy-using systems is an essential element of overall system efficiency. Building energy-using systems such as heating, cooling, ventilation and lighting provide thermal comfort, visual amenity, indoor air quality and other building services that ensure the effective functioning of buildings. The proper design, installation, commissioning and operation of the control system are essential to ensure that services are regulated in a manner that will both avoid excess energy use and provide effective service delivery. Ineffective control, however, is endemic in Europe's buildings, such that spaces are heated when it is not necessary, lighting is left on, ventilation operates continuously at maximum capacity, etc. The resulting energy wastage is vast, and thus a considerable potential for savings is presented.

In principle, modern building automated controls comprise a significant part of the solution, providing the possibility to control each of these elements individually and as a whole. Furthermore, they can respond to demand (need), and via information and communication technology (ICT) they can analyse building energy-using systems, diagnose problematic control issues as they occur and make intelligent responses to rectify them.

This is the promise − but reality has yet to match it fully. On average, building automated control technology undoubtedly saves significant amounts of energy, but when it is deployed it is saving much less than it should on account of numerous design, installation, commissioning, monitoring and operational failures. There are a variety of reasons for this. One of the principal aspects of this report is the exploration of these reasons, but the key theme is the need for control solutions that work better with people and the way they use and operate buildings. These solutions are not simply hardware-based: in many cases, especially for the more complex non-residential buildings, the whole manner in which controls are procured, designed and specified, installed, commissioned and managed within building services is in need of improvement, with the right incentives to deliver appropriate technical and organisational capacities, resulting in better facilities management for energy efficiency. The effective deployment of controls will thus be as much an organisational challenge as a technical challenge.

### *Current technologies and barriers to their implementation*

Modern building automation technology (BAT) brings the electromechanical hardware of sensors, actuators and thermostats together with ICT hardware such as controllers/outstations, programmers and central facilities such as personal computers (PCs) and data displays. Collectively these can be combined with appropriate software to provide building energy management systems (BEMS) for service sector (non-residential) buildings or home energy management systems (HEMS) for residential ones; however, it is important to understand that varying degrees of integration and sophistication are used and that the most appropriate system will vary in response to the building and usage characteristics.

There is a plethora of elements and systems configurations on the market with different levels of functionality and which use differing operational software, communication technology and protocols. The sheer variety of solutions that are available is one of the biggest hurdles to both broader adoption and improved implementation because the value proposition from automated controls becomes blurred between competing claims and is adversely affected by implementation problems that are exacerbated by insufficient standardisation. In part this diversity and complexity is also driven by the broader pace of developments in ICT more generally and simply reflects the widening array of possibilities that have become available as technology evolves; however, there is an ongoing tension between the emergence of new solutions and the need to standardise to facilitate deployment at scale and reduce implementation difficulties.

### *Barriers to energy savings*

Buildings, and the stakeholders involved with them, are complex. This introduces additional barriers beyond those that would apply to the adoption and use of any standard energy-efficient product. Split incentives may separate the economic incentive for energy savings from those that procure services, but even when these do not apply there are barriers associated with (i) awareness of options and value propositions, (ii) access to qualified personnel to design, install and commission automated controls, and (iii) the fact that poor implementation often goes undetected. For example, if heating and cooling set-points are too close, such that air conditioning cools a space while it is simultaneously being heated, users will not necessarily be aware of what is happening and are unlikely to complain unless thermal comfort is also affected. This all-too-common situation illustrates just one of the many implementation and operational failures that can occur and remain undetected with building energy controls, no matter what their degree of sophistication. Monitoring real performance and running diagnostics to detect faults and waste is a key need, requiring both (i) the installation of appropriate technology and (ii) the organisational structures and capacity to monitor faults and follow up with remedial action. The process of continuous commissioning, one example of the type of structures that are needed, implies a more profound service delivery than the simple installation and commissioning of building automated controls.

### *Market trends*

The European automated controls market has held steady throughout Europe's current economic recession, despite the fact that the natural installation opportunities are strongly related to new-build and renovation events, which are sensitive to broader economic trends. This is because renovation and renewal rates have increased slightly as building owners have become more sensitised to (i) the value of energy savings, (ii) the arrival of new technologies with additional value, and (iii) the impact of more proactive broader public policy measures, such as the EU's Energy Performance of Buildings Directive (EPBD), all of which have helped stimulate demand. Given these trends, penetration of modern BAT and management systems is projected to rise from 26% of all service sector floor area today to 40% by 2028 without further policy intervention. In the residential sector, penetration of HEMS is projected to rise from 2% of homes today to 40% by 2034 without additional intervention.

### *Savings potentials*

For the current report, three scenarios were developed to assess the potential for additional energy savings:

- the **Reference Scenario**, which assumes a continuation of current trends regarding the adoption and installation of BAT/BEMS in the service sector and BAT/HEMS in the residential sector, with no significant improvement in installation and management procedures
- the **Optimal Scenario**, which assumes an optimal level of installation and operation of BAT/BEMS or BAT/HEMS from a user cost-effectiveness perspective
- the **Recommended Action Scenario**, which assumes that the recommended actions outlined in this report (see section 7) are followed and that BAT/BEMS and BAT/HEMS are procured, installed and operated accordingly.

These scenarios were simulated for the European building stock in a purpose-built building energy stock model to estimate the expected impacts on building energy use and costs. While the results do not apply to the circumstances of specific individual buildings they do indicate the average expected outcome for the building stock as a whole. The potential energy savings from greater and more effective deployment of building automated controls is vast. The total techno-economic optimal savings potential as expressed through the Optimal Scenario is estimated to reach 22% of all building energy consumption by 2028 and to maintain that level thereafter; however, this is predicated on a rational and perfectly functioning market without serious constraints to effective service delivery. A more realistic depiction of the potential to deliver additional savings beyond the Reference Scenario (business-as-usual case) is offered by the Recommended Action Scenario. In this case, savings ramp up progressively over the scenario period to reach 13% of the Reference Scenario energy consumption by 2035 (Figure ES1). The savings under the Recommended Action Scenario are 74% of the savings under the Optimal Scenario for service sector buildings and 50% for residential buildings. The lower share of the full techno-economic potential that is thought to be realistically attainable for the residential sector is related to (i) the much greater scale of implementation (addressing 74% of total building floor area as opposed to 24% for the service sector), (ii) slightly less favourable payback periods and (iii) decision-making stakeholders that are slightly less accessible or receptive to investments designed to economise on costs. However, this also infers that the exploitable savings potential for the residential sector should continue to be realisable well beyond the scenario horizons of 2035 considered in this analysis.

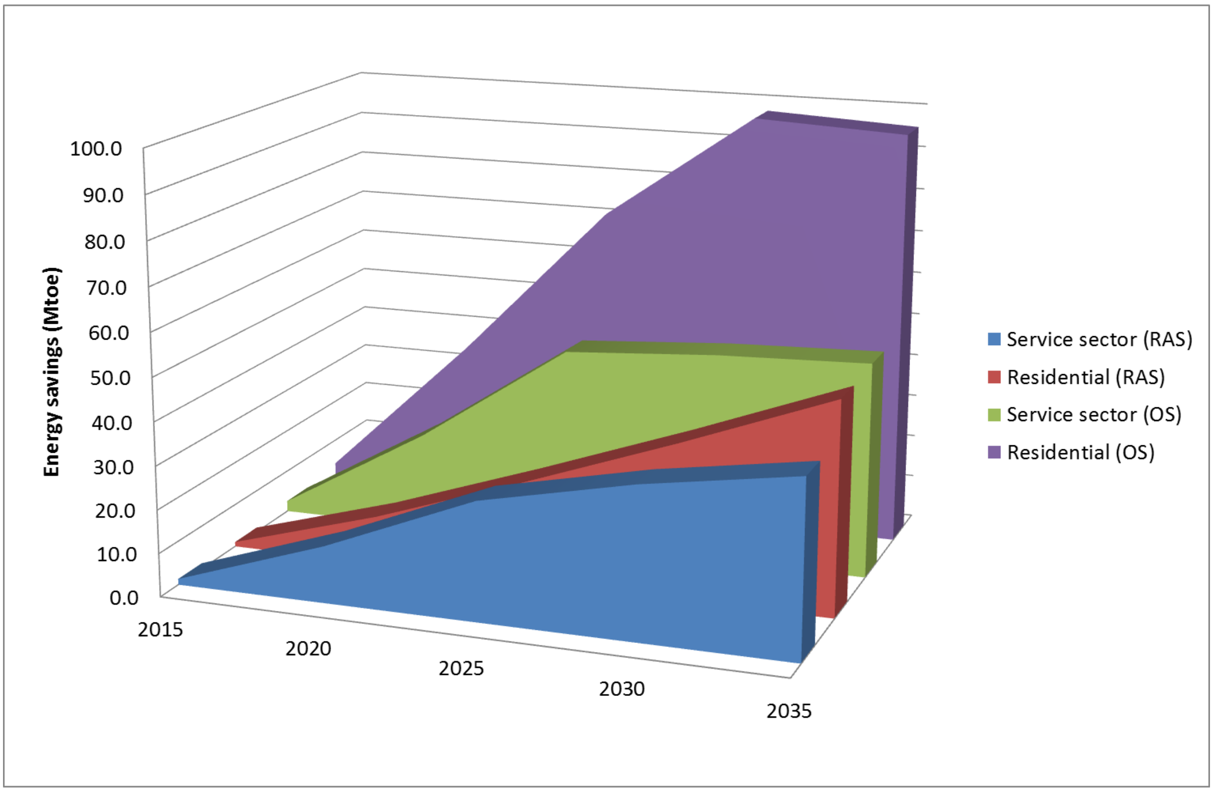
The Optimal Scenario leads to some 2 099 Mtoe of cumulative energy savings from 2013 to 2035 compared to the Reference Scenario for residential and service sector buildings combined. This equates to estimated cumulative $CO_2$ savings of 5.9 gigatonnes over the same period, with annual savings of 184 million tonnes of $CO_2$ in 2020 and 380 million tonnes in 2035[1].

By contrast, the Recommended Action Scenario leads to some 1 000 Mtoe of cumulative energy savings from 2013 to 2035 compared to the Reference Scenario for residential and service sector buildings combined. This equates to estimated cumulative $CO_2$ savings of 3.4 gigatonnes over the same period, with annual savings of 96 million tonnes of $CO_2$ in 2020 and 260 million tonnes in 2035.

Over the Recommended Action Scenario period (2013−2035), some €136 billion of extra investments in BAT and related services are needed to deliver these savings, at an average of €6.2 billion per year. Large as these incremental investments are, they are nine times less than the value of the resulting savings in energy bills, which total €1 187 billion over the period, at an average of €53.9 billion per year (Figure ES2).

[1] Assuming the same electricity sector fuel-mix and emissions factors as reported in the New Policies Scenario of the IEA's *World Energy Outlook 2012* (IEA 2012b).

**Figure ES1. Building energy savings under the Recommended Action Scenario (RAS) and Optimal Scenario (OS) for European residential and service sector buildings compared with the Reference Scenario.**

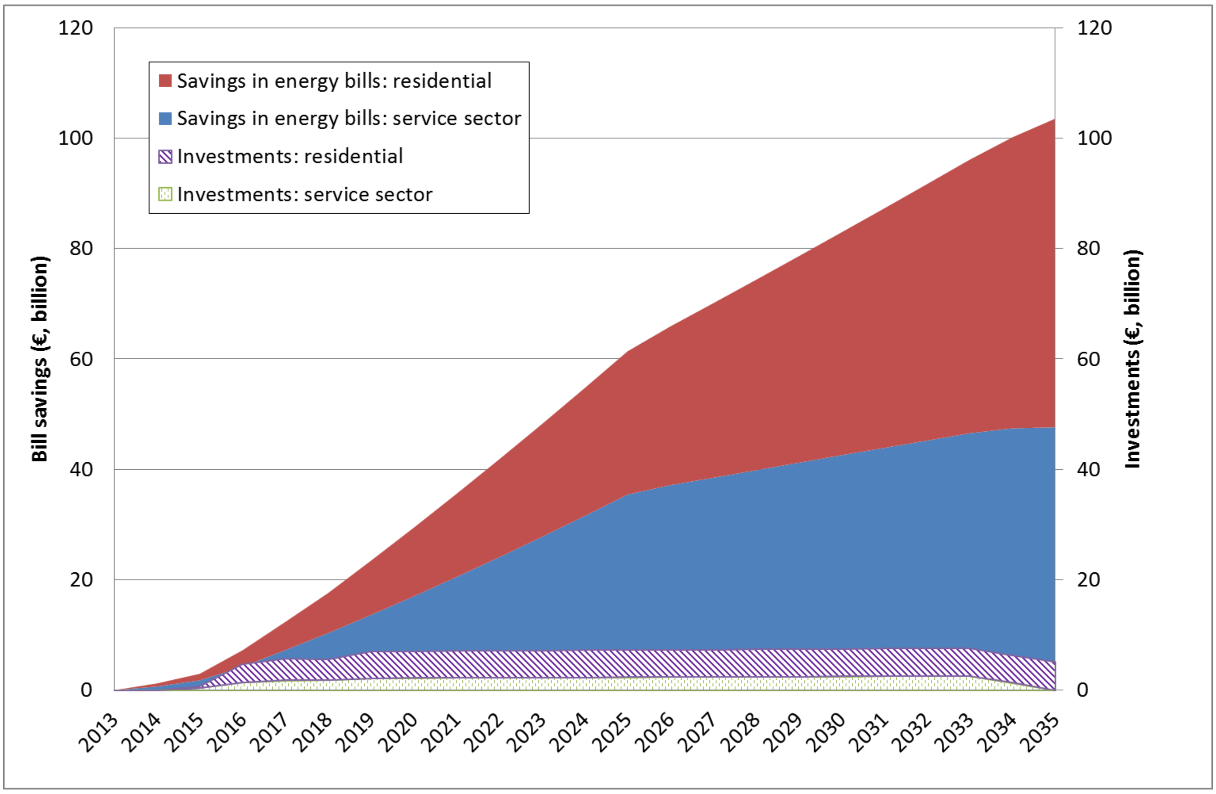



### *Recommended actions*

Impressive as these savings potentials are, they will not be realised without firm and proactive measures to stimulate both good practice and higher rates of deployment. Numerous approaches could be pursued to support the objectives, but this project has identified a range of complementary measures and proposed recommended actions:

- promote high-quality continuous commissioning
- promote development of advanced data-analysis techniques for system operation and energy-efficiency routes to market
- build capacity among building energy controls service providers and engineers
- strengthen interoperability and standardisation
- raise awareness in the market and education along the supply chain

**Figure ES2. Investments and energy bill savings achievable with building automated controls in European residential and service sector buildings under the Recommended Action Scenario.**




- develop targeted financial incentive mechanisms designed to stimulate supply and demand of quality BAT/BEMS/HEMS products and services at as fast a scale as can reasonably be sustained without risk of market poisoning through unqualified service delivery
- make use of and adapt existing policy levers, most importantly in the EU EPBD (Directive 2010/31/EU) and Energy Efficiency Directive (Directive 2012/27/EU).

The recommendations section in the main body of this report (see section 7) contains explicit suggestions regarding how these two Directives could be implemented, and also amended, to support greater energy savings through building automated controls that address building regulations, public sector buildings, public procurement, inspection of heating, ventilation and air conditioning (HVAC) systems, building stock renovations, utility energy-efficiency obligations, sub-metering, demand response, strengthening the cadre of qualified professionals and developing energy service markets. The EU Energy Labelling Directive (Directive 2010/30/EU) is also currently under review; this presents a timely opportunity to review the scope of the Directive and consider whether it is appropriate and feasible to develop EU mandatory or voluntary energy labelling requirements that could apply to BAT/BEMS/HEMS.

# 1. Introduction

Buildings are widely reported to consume 40% of all energy in Europe (EC 2010b). In recent years, they have received increasing attention by policymakers seeking means to reduce the energy requirements of the building stock. Much of the effort to date has focused on new construction and major alterations, tightening building regulations to improve the efficiency of the building fabric and the installed equipment. Legislation has also promoted renovation of the existing building stock, greater use of renewable energy, and the disclosure of energy performance (mostly modelled[2], not actual) via energy rating and labelling schemes. Very little attention has been paid to control systems, which is surprising given their potential to reduce building energy consumption substantially and rapidly, at relatively modest cost.

This report presents the findings of an analysis commissioned by the European Copper Institute (ECI) to examine the potential of building energy controls to accelerate energy savings. It demonstrates the undoubted potential of building automation technology (BAT) and controls to save large amounts of energy, with a technical potential of some 25% across the building stock, amounting to 10% of all energy use in the EU. However, it also cautions that to achieve this potential will require considerable improvements, not just in the technology (which already has great capabilities and is advancing rapidly) but in its effective application in buildings. Too often, BAT installations do not fulfil their promise, distancing users and management from the systems with which they need to interact.

There is also vast, unrealised potential in existing BAT systems. For example, most electronic building management systems (BMS) can be used for more effective control and energy management, but this is only happening in a small proportion of installations known to the authors of the current report − perhaps 10% in all. Effective deployment of BAT is therefore more about what people do − in designing, applying, integrating, installing, commissioning, handing over, operating and reviewing them − than the products themselves. This need for much better deployment is reflected in the recommendations in this report.

[2] This depends on the country in question and building type. In some countries, such as the German ENEV2014 regulations, a choice is given as to whether to determine building energy performance certificate ratings via measured consumption or via calculations, some, such as the French RT2012 regulations specify actual consumption base ratings, but many are based on calculated consumption.

# 2. Building automation technology and systems

## 2.1 Principal building energy uses and the role of control

Energy in buildings tends to be used for ten principal purposes, each of which presents problems and opportunities for energy-saving control.

1. **Heating** tends to be the largest single energy end use, particularly in domestic buildings. Opportunities for improved control include not just better programming and temperature control, but increasingly better control of plant, e.g. to reduce return water temperatures to condensing boilers and to optimise performance of systems with more than one source of heat.
2. **Hot water**. With the requirement for sterilisation against *Legionella*, many systems are now operated continuously at 60 °C, often unnecessarily. This can greatly increase energy consumption, by a factor of three or more in some offices known to the authors of this report. Control systems that provide an effective but economical periodic sterilisation regime, but which warn management when this has not been fulfilled, could be very rewarding. The performance of solar hot water systems is often undermined by poor integration with boilers and electric heaters, poor user interfaces and poor diagnostics.
3. **Ventilation**. There are many opportunities for better and more efficient ventilation that responds effectively to demand, e.g. as people move around a building. Heating and ventilation can also be poorly integrated, such that ventilation may start up to cool a space when the heating has not been turned off. Heat recovery systems, where fitted, can also benefit from diligent control to ensure they are working correctly and not creating a need for unnecessary heating or cooling.
4. **Cooling**. Much energy is wasted by heating, cooling and ventilation fighting each other. Case studies are not uncommon where heating, ventilation and air conditioning (HVAC) energy use is reduced by a factor of more than three once control-related faults are resolved. This can be as simple as setting an appropriate deadband between heating and cooling.
5. **Humidity control**. While only relatively few building have humidity control, where fitted it can be a major source of energy wastage if poorly controlled.
6. **Lighting**. Automatic lighting controls are now widely used, but too often less energy than anticipated is saved, and consumption sometimes even increases. Three major contributory reasons for this are:
   i) poor and poorly understood user interfaces
   ii) a tendency to switch on more lights than necessary (e.g. all the lights in a space when only some are needed, or all the lights to the design standard when the occupants would have been happy with fewer lights/less lighting)
   iii) all circulation lights switching on when any space is occupied; in general, there is still work to be done to ensure that more systems respond to demand and avoid defaulting to 'on'.
7. **Control and communication systems**. These are normally on all year round, but sometimes this is unnecessary. Controls need to use some of their sophistication to reduce their own energy use.
8. **Office and information technology (IT) equipment**. Much unnecessary use could be avoided with better control, but often this is seen to be nothing to do with the providers of buildings. Devices such as 'last out' isolating switches can save large amounts of energy.
9. **Audio-visual (AV) and entertainment equipment**. Much of this equipment defaults to 'on'.
10. **Catering and vending equipment**. This is an area that is often associated with a lot of wastage, e.g. vending machines left on continuously, or where ventilation of a catering kitchen starts at a

high speed at the beginning of the day, cooling the room too much and leading to staff responding by lighting the hobs etc. long before they are actually required.

## 2.2 Introduction to BAT

### *Definitions used in this report*

Definitions of automated building energy savings technologies are rather fluid and somewhat confusing. In this report, the following terms are used.

- BAT: building automation technology. This includes any kind of automated controls, from stand-alone thermostats and time switches to the most advanced technologies.
- BMS: building management systems. These bring together a range of building maintenance functions to a central point or points. Most commonly they include HVAC systems, but their functions can extend further and may include security, closed circuit television (CCTV), access, fire, safety and lighting controls. They are sometimes known as 'intelligent' BMS (IBMS) when incorporating functions other than HVAC.
- BEMS: building energy management systems. Most BMS have the capability of energy management, but not all are set up or used in this way, even if they have the inherent capability. The term 'BEMS' is therefore used in this report to refer to BMS that are optimised for energy-efficient operation, or definitely set up to manage building energy performance, in addition to the other functions described for BMS above.
- HEMS: home energy management systems. These are BEMS designed for use in the home.

### *The benefits of BAT*

The benefits of correctly designed, installed and operated BAT systems include the safe, efficient and effective control of building services installations to:

- provide good indoor conditions and services, to suit the needs of both management and users
- reduce energy consumption and running costs
- ensure equipment operates only when, where and to the extent actually required
- reduce ventilation and cooling requirements that arise when heat-producing equipment (e.g. lighting and motors) is used unnecessarily
- monitor systems and optimise their performance
- advise of problems, providing not just failure alarms but alerts to wasteful and unintended operation
- reduce levels of wear and tear and the costs of maintenance, repairs and replacement.

### *Controls in buildings*

Controls manage the operation of all types of building services, typically including:

- mechanical heating and hot water systems
- mechanical ventilation
- cooling and air conditioning
- natural ventilation systems, particularly motorised windows and dampers, often combined with mechanical systems in 'mixed mode' design, and sometimes including motorised shading
- lighting, including timing, occupancy detection, mood-setting, dimming and daylight integration, together with exterior lighting
- electrical systems, including time control, demand management and standby systems
- metering and monitoring systems, including heat and flow meters where appropriate
- communications, safety and security systems
- services to special areas and equipment, e.g. server rooms.

The provision of services may be determined by a variety of devices, often operating in conjunction. These devices include:

- **timers**, which range from straightforward on/off devices, through those that are programmable to allow different day/night or hour-by-hour settings throughout the day, to those that may also vary by day of the week or of the year
- **room controls** to register a request, e.g. light switches or dimmers, or push buttons to activate heating or ventilation (e.g. in a meeting room) for a timed period or until occupancy ceases
- **occupancy sensors**, which detect people in a space, with presence detection to switch equipment on when people arrive and/or absence detection to switch it off when spaces are empty
- **environmental sensors**, which detect, for example:
    - light levels: adjusting lighting and shading
    - temperature: adjusting heating/cooling/ventilation systems
    - humidity: adjusting ventilation and air-conditioning systems
    - air quality: adjusting ventilation systems.

These four types of device can be used in combination to create a sophisticated system where, for example, people turn on the lights when they need them, daylight sensing then dims them in relation to natural light levels, and occupancy sensors switch them off after the space is vacated. At the end of the day, a timer could enable the security lighting, but this would come on only when movement was detected.

Specifically, all this information can also feed into management systems of various kinds, in particular energy and maintenance management.

A typical control system will include the following hardware:

- **actuators**, for valves and dampers. They are generally controlled via an analogue signal, and can have a reversible motor so that they can be driven in each direction
- **communications network** linking outstations/controllers together, plus supervisors and, increasingly, other equipment via BACnet, etc. Actuators and sensors are normally hard wired to each controller/outstation, but communicating devices are becoming more widely available. Communications may connect with other systems, to receive security and fire alarms, for example, although fire alarms are normally hard wired via fire alarm interfaces
- **control valves** − these can be two, three or four port and control the flow in circuits and through heat emitters, etc. Valves are normally modulating for most control functions, although some are open/closed for isolation or more basic control functions
- **controllers or outstations**, which incorporate analogue and digital inputs/outputs to receive signals from sensors and send signals to plant and actuators in accordance with the control strategy. These may be single-purpose (e.g. a temperature controller for a fan-coil unit) or multi-functional (e.g. a typical BMS outstation, with a number of digital and analogue inputs and outputs that can be programmed to suit the specific installation). These outstations/controllers may stand alone or be connected to a communications network to form BMS
- **flow meters,** which can provide cumulative totals or instantaneous flows of gas, oil, water, etc. Cumulative flow totals are generally provided via pulsed signals
- **flow switches,** which provide a digital input to the controllers/outstations, or direct interlocks with plant
- **programmers and time switches** − used for basic time-control functions and commonly used for domestic heating controls
- **sensors**, which provide analogue inputs to the controllers/outstations with respect to temperature, humidity, $CO_2$, etc.
- **supervisors**, which link to the network and allow the status of the controllers to be observed or altered. The essence of BMS or BEMS is the inclusion of supervisors, so an installation can be not

just controlled, but monitored and managed. A network can contain several supervisors, ranging from a simple touch screen on the wall to server-based systems
- **thermostats**, which are used for basic control functions, such as most domestic heating controls, and are used for safety and limit controls.

Digital control systems will also include the necessary software to deliver the control strategy, which includes management of the following signals:

- **analogue inputs** from actuators for position feedback, setting knobs and, less frequently, plant
- **analogue outputs** to open a valve to the calculated extent, or to run a motor at a specific speed, typically using a 0−10 Volt signal
- **digital inputs** from plant and equipment to provide plant status, faults, etc., generally via variable-flow controllers (VFCs)
- **digital outputs**, signals to switch a piece of plant on or off.

At its simplest, a control system consists of a device such as a thermostat or humidistat that switches items on and off in response to a change in temperature or humidity. However, many controls are now microprocessor-based, with direct digital control (DDC) replacing former electromechanical, pneumatic or analogue controllers. Identification of devices can be confusing: for example, temperature sensors get called 'thermostats'.

Perhaps the main feature of BAT is that it allows a building's performance in terms of its services to be monitored and better controlled, with settings being changed quickly and effectively with the aid of computers. There is much talk of integration, as has been the case for decades. In practice, however, BMS and BEMS have tended to concentrate on HVAC services, with systems for other types of service kept largely separate. For example, lighting management systems not only tend to be independent but are seldom directly integrated with the controls of blinds, except perhaps indirectly by dimming in relation to natural light levels. Similarly, safety, security, communications and electrical systems tend to have their own protocols, specialists and requirements for integrity that make it difficult to blur the boundaries. What is more likely is that high-level information (e.g. current status, particularly for any alarms) is communicated from one system to another, so an operator can have an overview, but not full control, from one position. 'Dashboards', which show a wide range of input information on a single screen, are becoming increasingly popular.

Actual performance of an installed system depends upon not just the features and capabilities of the hardware itself, but the capabilities of the specifiers and the operators. Much depends on where the hardware is located, how controls are set, how well the management and user interfaces have been customised to suit their context of application, the extent to which systems warn of wasteful and unintended operation, and when and how often they are checked. There is a lot to get right. Where this does not happen, advanced controls can even become an obstacle to good performance.

Another problem is that of 'data smog', where large quantities of poor-quality data obscure the meaning of everything. Sadly, sub-metering systems tend to be prone to this, where they have not been properly tested and commissioned, and do not include redundant meters to provide double-checks of the veracity of the data conveyed.

### *Control system types*

Control systems used in buildings range from simple thermostats and programmers to BMS, also known as building automation systems (BAS), energy management systems (EMS) and building energy management systems (BEMS). In their more complex forms, BMS and their related sub-systems may have many thousands of points controlling large buildings and dispersed estates.

Domestic control systems traditionally have had a single room thermostat controlling the boiler and pump on/off, plus a programmer to set the stop and start times for heating and hot water systems. In the last few years, separate zones for living rooms and bedrooms have been introduced as part of building regulations in some EU countries. Similar control systems have often been used for small commercial buildings, such as shops, offices, cafés, bars, etc.

More sophisticated controls are available for domestic and small commercial buildings, including weather compensation, wireless zone-control systems, and home automation systems that can include curtain activation and incorporate AV systems etc. The home automation systems tend to be installed only in very expensive properties on account of their cost and comprise a very small part of the marketplace.

Most new control systems are now microprocessor-based, although there are still many installations with more traditional electromechanical time switches and programmers.

Most medium and large commercial and public buildings have a form of BMS with programmable or dedicated-function DDCs and outstations. However, older buildings such as schools can still have relatively basic stand-alone controls such as optimisers and compensators.

In addition to controls supplied by control manufacturers, an increasing number of control systems are supplied as part of the main plant, e.g. boilers, heat pumps, variable refrigerant flow (VRF) systems. These controls vary from relatively simple to quite sophisticated (for example, some boiler controllers sequence the boilers and also control hot water cylinders and several heating zones). They can work well where the application matches the controller functions, but they can be the cause of significant issues where there is a mismatch. Experience in the UK also suggests that support can be lacking where these controls are used outside of their countries of origin.

### *BEMS components*

Controllers, or outstations, are the primary elements of BEMS, which may include one or many outstations, each connected to its set of sensors, actuators and plant. An outstation contains:

- microprocessors, which can act as stand-alone devices, holding all software, settings and time schedules necessary to control all items connected to it and to communicate with the network
- ‘points’, connections to plant, sensors and actuators, comprising a set of inputs and outputs, both digital and analogue, to which characteristics can be assigned
- the necessary power supplies for the outstation, sensors and actuators.

A communications network links controllers to each other and to a PC supervisor. The ability to communicate can enhance overall control strategies, improves user interaction, and facilitates wider dissemination of information on system performance. The communications protocol may be proprietary, but standard protocols such as BACnet and Modbus are used increasingly to provide common standards and improved functionality.

Communication through the network is two-way. For example:

- control software and settings may be downloaded to an outstation by the central supervisor
- the outstation will send information on its status and settings to the central supervisor routinely, on demand, and if there is an alarm
- outstations may exchange information to enhance system performance.

If communications are disconnected, the outstation will continue to function (much like a stand-alone controller), but functions may no longer be optimised. For example, it might be tuning the performance of the plant it controls in relation to the outside temperature, collected by another outstation and transmitted to it, but with no communications, the outstation will retain the most recent value of external temperature, or a default value.

The supervisor 'head end' is normally a PC, used to record data and adjust equipment settings and sometimes now permits remote access via the Internet. Recent developments also include sensors, controllers and outstations with wireless, Ethernet or mobile phone gateways, allowing direct access to common communication systems, particularly the Internet.

BEMS permit easy review and adjustment of controls, offering: better comfort, properly balanced with efficient energy use (interestingly, surveys show that with good design, installation and management both aspects can be achieved); more efficient plant operation; and monitoring to assist energy management, early warnings of changed conditions, equipment faults and maintenance needs.

### *BEMS and energy efficiency*

Most of the energy-efficiency savings that can be realised via BEMS can be achieved by adhering to a few key principles. For example:

- only supply building services when, where and to the extent strictly required
- provide heating and cooling using the most efficient combinations of plant capacity[3]
- control areas or zones with different services requirements independently
- adjust internal settings according to external temperatures and light levels
- never provide heating and cooling simultaneously to the same area (except where dehumidification by cooling and subsequent reheating is essential and adequate deadbands are incorporated between heating and cooling)
- alert operators to unintended or wasteful operation of plant and systems.
- ensuring there is full demand-based control of plant.

Unfortunately, many installed systems do not comply with these principles. While this is a disappointment in terms of controls not achieving their full potential, it is also offers a massive opportunity for greater levels of energy saving from the more effective design, application and use of controls.

Appendix A reviews a number of control measures that can be used to improve the energy efficiency of HVAC systems, starting with boiler and chiller plant. It identifies where relatively conventional systems can go wrong and how performance can be improved. These measures relate to not just the control systems themselves, but how to configure the mechanical systems to be more controllable. The information is based largely on UK experience; while practice in some other EU countries may be better, discussions suggest that similar problems often do occur, albeit to a greater or lesser degree.

Given the poor performance of many conventional systems, problems tend to escalate when further complication is added, for instance integrating renewable with conventional systems, which can easily threaten the efficiency of both. This emphasises the need for much better practice in designing controls for low-energy buildings, and for policymakers to recognise the urgency of this if their strategic ambitions are to be achieved.

[3] Traditional boiler/chiller sequence-control systems endeavour to provide heating and cooling utilising the minimum number of boilers and chillers on line. Modern boilers and chillers, with their packaged modulating-capacity controls, are often more efficient at low loads than at full load, and hence more sophisticated control methods are required to optimise the efficiency of part-load operation. Unfortunately, many traditional sequence-control systems work poorly, and very few designers appreciate the modern control strategies that are required.

## 2.3 HEMS

The HEMS market can be considered to be comprised of stand-alone systems, networked systems and in-home displays.

- **Stand-alone systems** will typically consist of sensors and an information display that communicates with the sensors and utility meters. More advanced systems will have a central management system that collects consumption data from multiple devices and enables their control via standard consumer IT devices, such as smartphones or PCs.
- **Networked systems** establish communication between HEMS and energy utilities and are designed to enable demand response, i.e. to enable consumers to modify demand in response to time-dynamic tariffs. Networked systems are more costly to install and require consumer willingness to cooperate with the utility to modify their energy use. While they have been trialled, they are currently much less common than stand-alone systems.
- **In-home display systems** simply display energy meter data in real time to show how much energy is being used in the home. They neither directly control the energy-using equipment nor display information on specific end uses, but they do allow consumers to attempt to correlate the consumption profile with the operation of equipment and thence make manual adjustments to equipment to regulate energy use.

In-home displays are thus a means for increasing information on home energy use; however, they are not really a building automated control technology as they do not control the energy-using equipment. Therefore, they are not really considered to be a full BAT system/HEMS and hence are not included in the estimates of product penetrations and savings potentials considered in section 5 of this report.

The control provided by stand-alone and networked HEMS are supported by intelligent device controllers such as smart thermostats, also known as ‘programmable communicating thermostats’, which have the ability to send and receive information wirelessly. They can not only be remotely controlled via consumer ICT devices but can also be set to provide operation on demand, i.e. when a space is occupied. Similarly, plant such as boilers, air conditioning and ventilation systems can be managed by device-level controllers that connect and communicate via a standards communications technology and protocol (see the section entitled ‘HEMS technology standards’ below).

The more advanced HEMS will also have sensors/controllers that allow sensing, monitoring and control of other equipment besides HVAC, including lighting and appliances, but this functionality comes at an extra cost and its economic viability is less proven.

### *HEMS technology standards*

HEMS currently make use of a variety of industrial communications standards and related technologies designed to facilitate interoperability and deployment. Communication can function via powerline carrier (PLC) technology, which makes use of existing wiring in the home, or via various wireless technologies, as described below.

1. HomePlug allows the networking of devices through existing electrical wiring in a building. This PLC technology provides for the distribution of high-speed internet access, music, video and smart energy applications, with data transfer rates of up to 200 Mbps.

2. ZigBee is a standards-based wireless technology for use with low-cost, low-power sensors and controllers in personal area networks and home energy home area networks (HANS). Its applications include building operations, lighting, remote control, telecommunications, etc. It is able to penetrate walls and has transmittance distances ranging from 10 to 1 600 m.

3. Z-Wave is a modular, battery-operated, mesh technology suitable for low-speed controls (e.g. changing the controls on a device, including raising/lowering settings or switching on/off)

and allows consumers to control home electronics devices (e.g. appliances, lighting, HVAC, home security) remotely via mobile phones and computers. It incorporates the devices into an integrated wireless network and does not interfere with Wi-Fi or other networks as it operates at a completely different wavelength. Its range is approximately 30 m and it is suitable for HEMS.

4. Wi-Fi operates at a higher frequency than ZigBee and is therefore less able to penetrate through walls; it also requires greater energy input. However, it plays an important role in HEMS, not least because it is the networking technology that is most well-known to consumers.

Each of these technology standards is backed by consortia of industry players that have often formalised alliances. The Z-Wave Alliance currently (2013) has 141 full members and 57 affiliates, whereas the Zigbee Alliance has an even larger membership (promoters, participants and adopters). The HomePlug Alliance currently has 58 member companies and 187 certified products utilising the technology. The alliance members have developed the HomePlug Green PHY™ PLC networking specification to facilitate interoperability between powerline-based technologies and to target smart grid and smart energy applications. HomePlug has been used together with ZigBee in a common application layer solution by the Smart Energy Initiative (a utilities-based body) for use in an advanced metering infrastructure and HANs.

## 2.4 Recent and future developments in controls and BMS

The building services controls industry in Europe has developed relatively slowly compared with other industries that use microprocessor-based technologies and communications. The principal reasons include:

- insufficient general awareness, understanding and appreciation of the importance of HVAC control systems
- a slow response from HVAC equipment manufacturers to incorporate advances in their packaged controls and communications
- a lack of standards that would allow BMS suppliers to develop more universal products
- poor standards of specification, resulting in lowest-cost solutions regardless of the effects
- the current, poor economic situation, which is suppressing new build, retrofit and refurbishment rates.

### *HVAC equipment manufacturers*

HVAC equipment manufacturers have started to incorporate greater control functionality and communications into their products within the last few years. This trend is likely to increase and has both advantages and disadvantages.

Boiler, combined heat and power (CHP), chiller and VRF manufacturers, for example, offer a vast range of products with very different control and communication capabilities. Some have sophisticated control systems that offer a high degree of flexibility and incorporate communications standards such as BACnet. Others can be as basic as on/off from a programmer/time switch with the possibility of a volt-free contact for an alarm.

The growing trend to packaged controls is likely to result in many unsatisfactory control systems. The control sophistication, functionality and communications needs to be appropriate for the item of equipment: in many cases simple on/off and alarms are sufficient. However, manufacturers increasingly offer additional functionality, which may suit some applications but not others. Many systems have limited or no potential to communicate with other systems such as BMS. The problems that arise are often compounded by a lack of understanding of the product by suppliers.

A number of equipment manufacturers are far more enlightened, offering good communication standards and even smartphone applications to communicate with their products. Unfortunately these are in the minority.

Some air-handling unit (AHU) manufacturers, however, have found that offering standard controls without communications limits their sales potential and so they now offer standard BMS outstations with BACnet communications either as standard or as an option.

### *Controls manufacturers*

Manufacturers of control systems offer a vast array of products ranging from simple programmers through to sophisticated BMS solutions with potential communications to thousands of points in buildings located across the globe. While products have been developed in recent years, the rate of change has been relatively slow. The major changes have been associated with communications. Some of the smaller, more specialist manufacturers have developed new products, and there have been advances with control valves allowing remote commissioning of flow rates etc.

### *Communications*

Communications have improved significantly in recent years from dial-up modems to high-speed broadband and internet protocol (IP) addressing via Ethernet networks. Text messaging services etc. are also available with BMS. Wireless communications can be useful for some applications, particularly retrofit, but can have issues that would not occur with hard-wired systems.

BMS used proprietary communication standards between head ends and outstations/controllers for many years with limited communication between systems and plant; typically, digital inputs and outputs were used with some analogue connections. Gateways have been developed for around the last 20 years to connect to equipment and other controls systems, such as lighting controls.

The most significant communications development is BACnet, a standard set of protocols developed over many years in the USA under the auspices of ASHRAE. It is now the most common standard for communications between different systems, normally requiring the least configuration to provide the required functionality. Certified products meeting the relevant standards are available. BACnet is available in various formats with BACnet/IP typically used for the high-level networks.

Other common communication protocols include LonWorks®, Konnex (KNX), S-Mode (instabus EIB), M-bus, Modbus, OPC, oBix, etc. These are most commonly used for connection of third-party devices and systems. Modbus has been common for connection of larger plant items but is generally being overtaken by BACnet. M-bus is commonly used for metering.

A number of software products link many communication networks and provide a common platform for building automation, including associated services such as security. They are sometime referred to as ‘middleware’. The most common is probably Tridium, with over 350 000 applications of its Niagara framework installed worldwide. Developed in the USA, it has an increasing European presence.

Communications will play an increasingly important part in future control and monitoring systems; however, the danger is that the industry, specifiers and end clients concentrate on the high tech without getting the basics, such as system controllability, correct. Many of the developments are now led from the USA, which has a larger marketplace, but not all systems developed there are directly applicable to the European marketplace. European manufacturers and bodies such as relevant institutes need to ensure European interests are upheld.

### *Data/performance analysis*

Improved communication allows the collection of vast amounts of data that could be used to improve the performance of buildings. Building regulations and standards such as BREEAM in the UK and LEED in the USA are increasing the sub-metering of electrical consumption and, to a lesser degree, the sub-metering of heating and cooling. However, in use these systems, designed to meet a regulatory requirement not a business need, have often been found to have been poorly commissioned (if at all) and lacking in functionality. Smart metering is becoming more common, and there are many products such as energy dashboards that provide an insight into energy use in buildings.

Many of the data on building performance are not collected and many that are collected are not effectively used. Many, although not all, energy dashboards and similar products primarily consider consumption data and may relate these to weather conditions but rarely consider actual control and operation of the buildings.

A research project for DETR/BRECSU in the UK during the late 1990s involved mining of the data available from BMS for a number of typical buildings. Data were downloaded from the buildings via dial-up modems and then analysed off line. Relationships/patterns could be identified from the data directly relating to the performance of the buildings. For instance, in a large complex building with a team of maintenance staff, the AHU damper position was closely associated with increased energy consumption. When this was checked, the damper linkage was found to be disconnected, thus causing the energy waste. The company that took this forward commercially floundered for other reasons, and these techniques have never taken off in the UK or Europe for building applications, although they are used in process industries. However, a number of companies in the USA are developing products that use data-mining techniques, no doubt in conjunction with other software developments, and these are beginning to look very interesting. They take advantage of recent communications protocols and can gather vast numbers of data, assisting in the identification of performance trends and the associated causes. Data mining and associated performance-analysis techniques have vast potential to improve the ongoing performance of buildings.

There are signs of products that could take advantage of the data available from BMS and make better use of meter data coming onto the market. However, published information is relatively superficial compared with information on US products. The European market appears to be somewhat behind the USA and is in need of stimulation to develop interest and products.

### *Control function standard software*

A number of BMS use logic modules for control strategies, enabling more rapid configuration of systems and providing the opportunity for strategies to be checked by others, such as consultants, specifiers, users, etc. Many systems still rely on commissioning and project engineers writing the control programs line by line. Obviously most programs will be copied from other projects or standards, but there is far greater potential for error. Some suppliers have built market share through the development and use of logic modules for control strategies, and this was one factor in the rapid take-up by systems integrators.

To date, while communication protocols such as BACnet have taken a significant step forward, no similar standardisation has occurred with control programming.

BMS programming takes the form of either logic diagrams or, more commonly, line-by-line programming. There are basic standards for logic diagrams such as IEC 60617-12, which in common with early industry standards has rectangular outlines for all types of gate and allows representation of a much wider range of devices than is possible with the traditional symbols. IEC 60617-12 was adopted by other standards, such as EN 60617-12:1999 in Europe; however, these have not been universally developed for building management application.

There is a call for a common programming language and loading protocols, emanating again from the USA, but realisation is a long way off. There might be an opportunity for Europe to lead the way and develop standard logic diagrams that could be adapted by manufacturers/suppliers. This would enable systems integrators and more knowledgeable end clients to be able to programme control strategies from one make to another without additional training.

### *Specifications*

Controls specifications are generally written by mechanical and electrical (M&E) consultants and are often poorly written on account of poor understanding of controls. In many cases, general specification clauses are used from standard specifications with very little thought given to overall requirements.

The standard specifications available as part of standard M&E specification writing tools tend to be poor. They include immense levels of detail and numerous options but are not well structured and result in specifications that are difficult to follow even when they have been correctly completed.

### *EN 15232: a building automation and control system standard for Europe*

The process of developing the EU's Energy Performance of Buildings Directive (EPBD) (EC 2002, 2010) has led to the derivation of whole building system energy performance standards. This is supported by a suite of approximately 40 technical standards that are designed to enable the whole building energy performance to be calculated in a harmonised way across Europe. Separate standards are used to derive the energy performance impact of each building system sub-element, e.g.:

- heating, EN 15316-1 and EN 15316-4
- domestic hot water, EN 15316-3
- cooling, EN 15243
- ventilation, EN 15241
- lighting, EN 15193.

The impact of controls is assessed using the standard EN 15232 (CEN 2012), which provides guidance on how to include building automated control and building management within the overall whole building energy impact assessment method. It includes:

- a detailed list of the control, building automation and technical building management functions that have an impact on building energy performance
- a methodology to enable the definition of minimum requirements regarding these functions to be implemented in buildings of different complexities
- detailed methods to assess the impact of these functions on the energy performance of a given building − these methods facilitate accounting for the impact of these functions in the calculation of whole building energy performance ratings
- a simplified method to get a first estimation of the impact of these functions on the energy performance of typical buildings.

Thus this standard is designed to facilitate the specification of control requirements within European building regulations and energy performance rating specifications.

This standard was developed through the European Standards body CEN, specifically CEN/TC247 (tasked with standardisation of building automation and building management in residential and non-residential buildings) and is published by the individual national standards bodies such as DIN in Germany and BSI in the UK.

TC247 has also developed other relevant European and international standards for building automation, controls and building management, including:

- product standards for electronic control equipment in the field of HVAC applications (e.g. EN 15500)

- EN ISO 16484-3: standardisation of BACS functions (used to assess the impact of BACS on energy efficiency)
- open data communication protocols for BACS (e.g. EN ISO 16484-5: 2012), which is necessary for integrated functions with BACS impact on energy efficiency
- specification requirements for integrated systems (EN ISO 16484-7).

Furthermore, these standards complement broader energy management practice and procedures which are addressed through the standard EN ISO 50001: 2011 “Energy management systems — Requirements with guidance for use”. This specifies requirements for establishing, implementing, maintaining and improving an energy management system, whose purpose is to enable an organization to follow a systematic approach in achieving continual improvement of energy performance, including energy efficiency, energy use and consumption. It specifies requirements applicable to energy use and consumption, including measurement, documentation and reporting, design and procurement practices for equipment, systems, processes and personnel that contribute to energy performance. The EN ISO 50001 standard supersedes the previous EN 16001:2009 standard.

### *eu.bac certification and labelling scheme*

The European Building Automation Controls Association (eu.bac) has established a product certification scheme for the rated performance of building controls equipment tested under EN 15500/ISO 16484-3 (www.eu.bac.org). Eu.bac provides certification of products to various applicable EN standards concerning building automation and control products. Certification is currently available for individual zone controllers and electronic radiator controllers and will shortly be available for other heating controllers and sensors. This has been complemented with a voluntary product energy labelling system (Figure 1). Certification of more product types is also planned in the near future. The goal of this certification is to assure that energy efficient functionality is provided by the products.

While the certification of the energy performance functionality of products is important it will not be possible for all types of products used in a BACS installation; nor does it cover the system wide aspects of energy efficient control of a building.

### *Certification Procedure for Building Automation Systems*

To address this voluntary certification and labelling has also recently been established for the control system as a whole (see Figure 2).

The procedure for eu.bac certification is designed as a three step process:

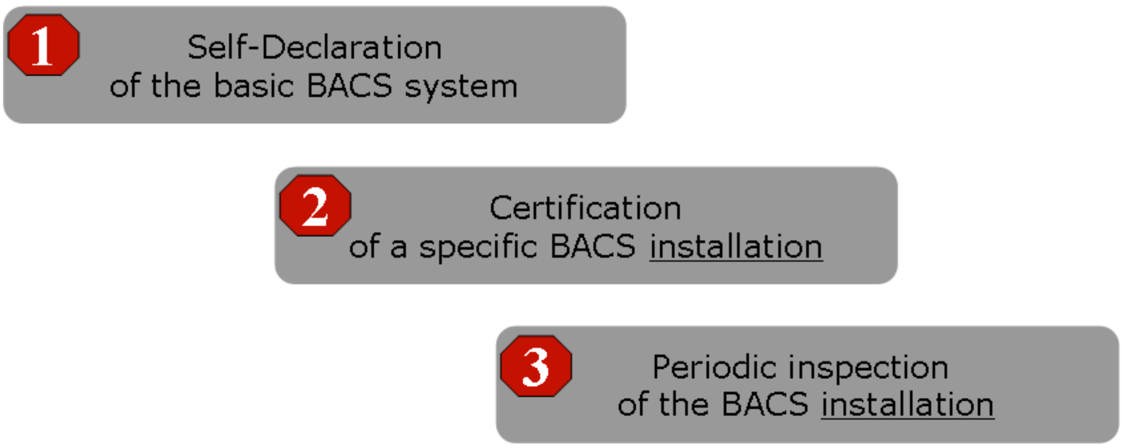
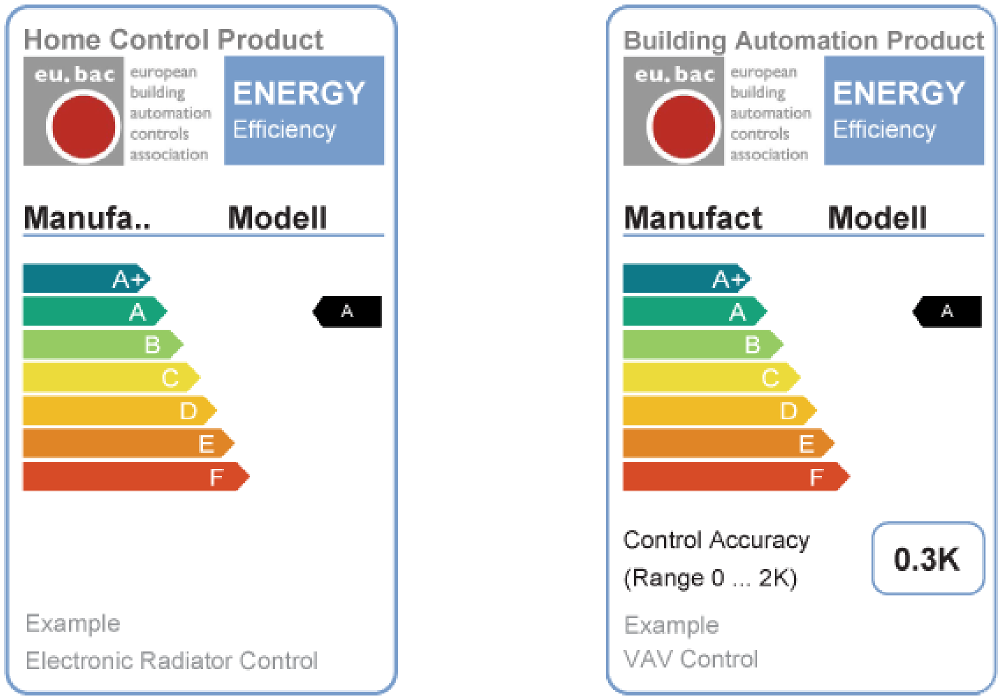


**Figure 1. eu.bac voluntary energy labels for automated control components (left: electronic radiator controls; right: variable air volume (VAV) controls).**




The first step is a self-declaration by the provider of BACS that a particular system is capable of delivering the functionality described in the Technical Recommendations. For a manufacturer of BACS this will typically be a self-declaration for a specific product family, while for a systems integrator it may be for the mix of products that is provided. The self-declarations will be made available in the eu.bac website. Nevertheless it must be understood that a BACS only can provide such functionality where the corresponding physical equipment has been installed and is working properly, e.g. presence detectors must be present to provide demand based control.

The second step is the certification of a BACS installation in a specific building. This is done by an authorized inspector who makes a site visit. As a starting point for the inspection the inspector should receive a check-list prepared by the building owner or maybe more often by the systems integrator. The purpose of the inspection is to verify that the claimed functionality is available in the building and that it is functional. The performance of the functions is most likely not evaluated in this step because there is normally no historical measurement data available. However if key performance indicator logic had been implemented earlier historical values would be available for performance assessments.

The third step is the periodic inspection of the BACS installation. This is to verify that the certified functionality is still available and working properly. If this is not the case the inspector will notify eu.bac who will require the building owner to recertify the installed BACS, or the certificate will end.

**Figure 2. eu.bac voluntary energy labels for automated control systems (building automation systems).**

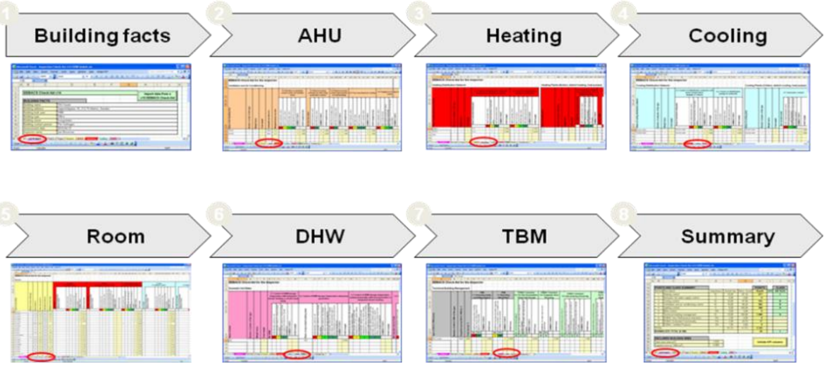

However, the main purpose of the periodic inspection is to evaluate the energy performance of the BACS, and of the building as a whole. This is done with the help of key performance indicators that will help to diagnose and understand the performance of the installed systems and to reveal when infringements of expected performance (in terms of functionally and energy performance) occur.

The periodic inspection helps counteract the fact that the energy performance of systems has a tendency to deteriorate unless they are properly maintained. This is an inherent issue because of the analogue and mechanical nature of the installed systems.

### *Technical Recommendations*

EN 15232 provides the basis for the certification. For the purpose of certification the requirements arising from application of EN 15232 are described in a Technical Recommendations document, which explains how to interpret and inspect EN 15232 functionality. It contains detailed descriptions of each function addressing the target of the function, conditions, different operating modes, what the inspector should check, etc.

### *BACS Inspection and classification*




According to the methodology of EN 15232 a checklist allows an auditor to inspect all performance factors i.e. relevant control components and their weight in regard to space size, usage profile and effective implemented functionality. Information on the building type (which determines a number of aspects e.g. the importance of individual functions against each other) and other site relevant date is also filled in by the auditor.

The workflow is oriented according to the energy flow in the building. The performance and impact of all control components are added up (according to their relevance e.g. in terms of space and usage) to derive an overall BACS rating. The checklist continuously adds the parts up while maintaining an “open action list” for areas the auditor still has data to enter. While interviewing a site specialist and visiting plant rooms the checklist gets completed and the result is calculated in the “summary page” right on the spot. Before completion the critical (most energy relevant) areas are reviewed with local operations to avoid mistakes, misunderstandings or bugs while entering data.

The overall result is expressed in terms of a normalized score between 0 and 100. As an approximate evaluation the calculation of an expected energy reduction (after improvement) is an estimation based on the efficiency factors taken from EN 15232 in combination with a weighted calculation model. The conclusion is that each additional 10 points on the normalised score will result in up to a 5% reduction in energy use. The actually achievable reduction in the real operating environment may differ from this, because of a different usage profile than the assumed one for instance, but this calculated value allows at least a rough estimation of the impact of intended improvements.

### *Summary*

The core functions of a building automation system are the control and automation of heating, cooling, air-conditioning, lighting and shading building systems. Well-designed and maintained systems attain the desired level of comfort and, at the same time, optimise the energy consumption.

The eu.bac System audit and resulting declaration assures compliance with the specified energy-efficiency class of the building automation system according to EN15232. The eu.bac System audit methodology incorporates a scientifically-tested assessment tool. The audit can only be conducted by expertly trained eu.bac authorised auditors. The holistic audit procedure tracks the energy flow in the building and addresses the parts of the building related to energy and comfort considerations.

The EUBAC Certification Scheme promotes improved energy efficiency of Building Automation and Control Systems because it provides guidelines to energy efficient functionality, provides a mechanism to check that a BACS installation includes the expected functionality, and maybe most importantly of all, that with periodic inspections the functionality provides equal or better performance over time.

### ***European Demand Connection Code and demand response***

Under the auspices of the third package of European energy legislation, the European Demand Connection Code (DCC) is being established as part of the European Commission’s efforts to integrate European electricity and gas markets. The DCC intends to define requirements and minimum standards applicable to significant grid users (on the demand side), including in relation to system balancing. The initial proposals included provisions for the control of appliances to support system frequency control that are intended to facilitate demand response. There is an active discussion among transmission system operators and the appliance industry regarding the cost benefit analyses applied in these proposals; it is currently unclear how these will be resolved and hence the impact this initiative will have on creating demand response capability.

The eu.bac System method offers support in the design, commissioning and operation of an energy-efficient building automation system, thus providing considerable added value in the different phases throughout the life-cycle of the system. Continuous, automated evaluation of key performance indicators (KPIs) for efficient operation allows the ongoing identification of improvement areas

These efforts are undoubtedly welcome in order to bring some systematic transparency to the market; however, as industry-led voluntary initiatives, they do not carry the same weight as EU-mandated labelling efforts, which when implemented apply to all products on the European market. It is therefore to be hoped that the recently initiated review of the European Energy Labelling Directive (EC 2010a) being conducted by Ecofys and Waide Strategic Efficiency for the European Commission will cover the current scope of the Directive to determine whether labelling of such energy-related equipment would be appropriate to address within the EU labelling framework.

# 3. Human factors in building energy controls

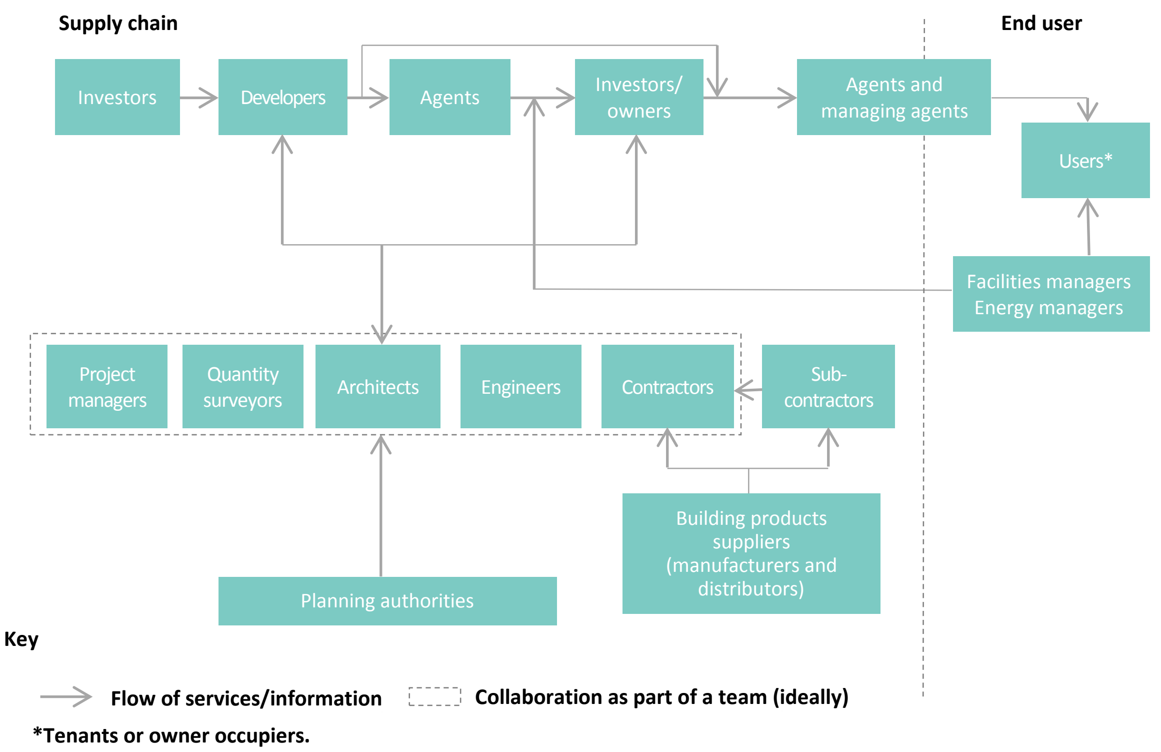
In spite of its undoubted potential, advanced control and monitoring technology does not inevitably produce good results. Time and again, studies of building performance in use reveal that controls create problems too, sometimes so severe that occupants and management are confused and energy and other operating costs increase in relation to simpler, more straightforward systems.

There is therefore a need to promote not just the adoption of advanced controls, but the adoption of appropriate and effective controls that actually work, including the factors for success in their deployment. The opportunities and barriers are both technical and managerial. The strategies and policies of governments and business leaders for energy and carbon saving with advanced controls will not be realised without:

- a recognition that understanding the control technology alone is not enough to realise its full potential; the specifier also needs in-depth understanding of the systems to be controlled
- educating engineers and technicians at all levels not just about the technical aspects of advanced controls, but on how to achieve the benefits in practical situations
- appropriate motivational training and mentoring for designers and operators
- competent, well-trained operation and management technicians with a desire to deliver the benefits that can result from the appropriate applications of the technology
- operation and maintenance (O&M) service contracts that reward the service provider for using BAT to limit energy consumption to that needed to deliver the occupier's business plan.

To understand the complexity of the environment involved in the design, procurement, installation, commissioning and operation of building controls, it is appropriate to consider the range of actors involved in the supply chain for non-domestic buildings (Figure 3).

**Figure 3. Non-domestic buildings sector: supply chain and end users (reproduced with permission from Carbon Trust 2009).**



BAT often fails to deliver its full potential because those specifying the system have limited understanding of how it will be operated. This problem is compounded by a lack of training of building O&M teams on the operation of the building services engineering (BSE) systems and the BAT that is intended to control and monitor them. A successful building is one that meets the business requirements of the owner and the occupier, and works well for its occupants in providing a pleasant safe, comfortable environment for its occupants while keeping its adverse environmental impact, energy use and carbon emission to a minimum.

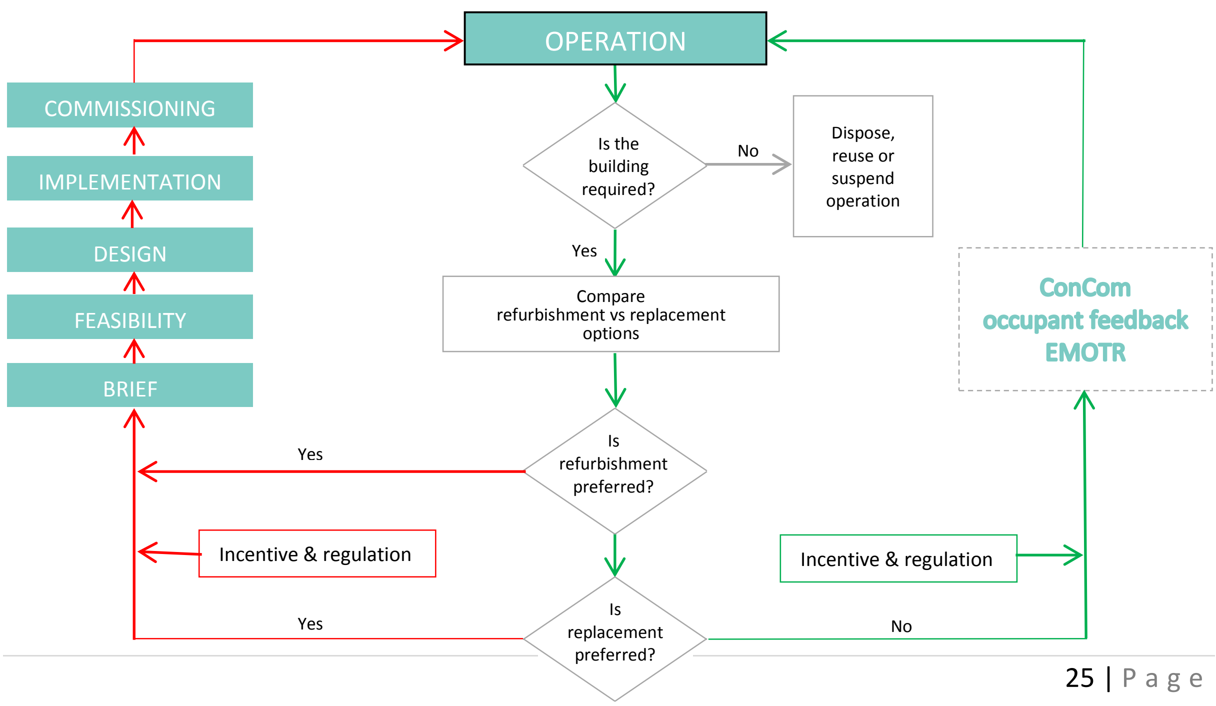
Focus should be upon the following human interface/operation considerations, which can be delivered individually or as part of a broader continuous commissioning programme:

i) briefing and the building life cycle
ii) best practice procurement
iii) occupant/user feedback
iv) design and implementation
v) lifetime product management
vi) O&M
vii) performance-based service provision
viii) real-time energy monitoring and continuous commissioning.

### *Briefing and the building life cycle*

Influential operational input throughout all stages of a project, but particularly at the project definition and briefing stages, will do more to enhance the benefits of BAT than any other single action. The building life-cycle diagram in Figure 4 includes the main project procurement stages. For success, each stage must address the implications for BAT in operation. The information collected from continuous commissioning, occupant feedback and real-time energy monitoring, optimising, targeting and reporting (EMOTR) in the green feedback loop in Figure 4 should be used to determine the brief for new-build and replacement projects. The feedback information obtained from this process can be used to inform the brief on all projects of the same or similar function as those from which the information has been obtained.

**Figure 4. The building life cycle (ConCom = continuous commissioning; EMOTR = energy monitoring, optimising, targeting and reporting).**

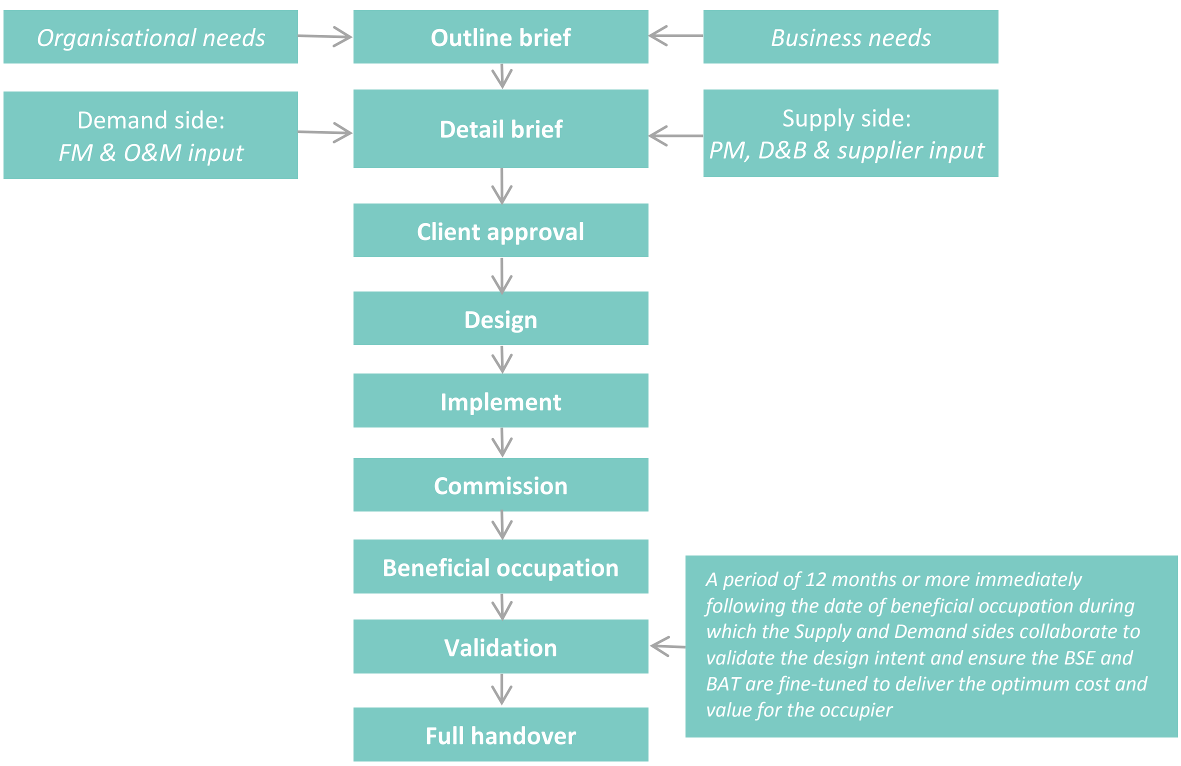


For example, if the feedback is from air-conditioned city centre office buildings, most of the information obtained is likely to be relevant to all such facilities.

### *Best practice procurement*

There are many building procurement options in use throughout the EU. The option used is less important to the outcome for BAT than is having the right level of influential operational and management expertise throughout. The main stages of best practice procurement are shown in Figure 5.

**Figure 5. Best practice procurement (FM = facility management; O&M = operation and maintenance; PM = project management; D&B = design and build).**



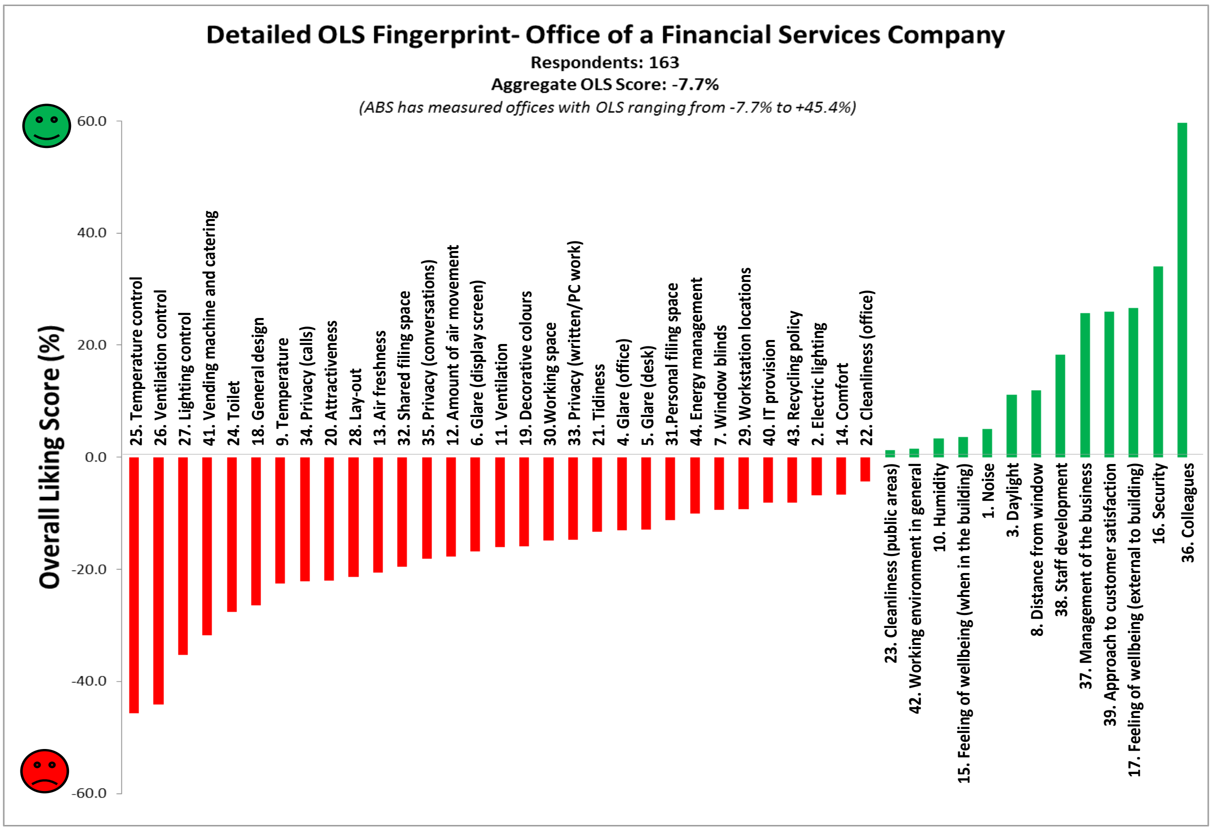

For best results it is essential that the demand side maintains a detailed involvement throughout the complete procurement programme. Their main task is to ensure that an operation strategy such as continuous commissioning is embedded in the procurement process at briefing stage and developed to a detailed operation strategy in readiness for occupation.

### *Occupant/user feedback*

The most important input to the brief for a new project comes from formal and anecdotal feedback from occupants of facilities that are to be replaced by the new project. Such information can also be used for new facilities where the specific occupier is unknown but the type of occupier is known. For example, occupant feedback from an office can provide valuable input to the brief for an office development that will not have a tenant at the briefing stage. The feedback does not have to be specific to the occupier, but it does need to be specific to the type of occupancy.

Formal occupant feedback is particularly helpful to facilities managers as it identifies areas of concern that are often caused by poor performance of BSE systems and their associated BAT. Occupant feedback on aspects of office occupation was collected in a survey of 11 UK offices conducted by ABS Consulting using a process called Overall Liking Score (OLS). Respondents perceived BSE and BAT to be major sources of dissatisfaction. None of these offices would have been designed or operated with the intention of achieving poor scores for BSE and BAT. Therefore, if the cause of the poor scores can be identified, strategies for improvement can be developed and implemented. Even in the best office the scores for BSE and BAT were negative and perceived by occupants as sources of dissatisfaction. In both the best and worst (Figure 6) cases, the response to the business culture questions were positive, showing respondent support for the business and its management. This gives some confidence that the negative responses were genuine: why would respondents who support the business and like the management, exaggerate negative aspects?

**Figure 6. Occupant feedback on aspects of office occupation in the UK: results for the office with the lowest score from a sample of 11 office facilities (OLS = Overall Liking Score).**




The best and worst offices in the sample had many similarities:

- full air conditioning that was nearing the end of its economic service life
- town centre locations in South-East England surrounded by busy roads
- shortage of funding for investment in improvements to the BAT
- old BAT that was obsolescent, and poor records
- prescriptive input maintenance contracts with no specific requirement for operation or energy efficiency
- inadequate technical expertise of the facilities management and maintenance team
- no stated carbon and energy management policy or strategy.

When the survey results were presented to management, a plan for improvement was implemented and some funding was provided for an improved operating strategy using continuous commissioning.

### *Design and implementation*

The best design can only come from a thorough understanding of operation. With validation included in the procurement contract, the designer, installer and manufacturer are intimately involved with operation during the first 12 months or more of occupation. Involvement in validation enables the supply side to learn from rich and immediate feedback on the how the specified design and products perform in operation. This will help to ensure that BAT delivers or exceeds the energy savings, carbon reduction and occupant satisfaction intended by the design.

### *Lifetime product management*

Lifetime product management is a form of private finance initiative for individual systems that form part of a building. It is particularly applicable for BAT in situations where the client wishes to benefit from the service that the BAT will provide but does not own it. The approach is based on the lifetime concept: integration and feedback between product marketing, development, manufacture, installation, commissioning, operation, decommissioning and disposal. The customer pays the manufacturer a sum over the duration of the contract, based on predetermined through-life performance.

With lifetime product management the end user buys the benefits from BAT rather than the BAT product itself. The process provides the manufacturer with valuable feedback on its products in operation and as a result accelerates innovation. Quality and reliability improve because the manufacturer carries the main financial risk of its product's reliability. Therefore, the quality of product and service will have a direct relationship with risk throughout the life of the contract, creating a bias to whole-life value rather than first cost. Only manufacturers with reliable products will survive. Therefore, through a process of evolution, poor-quality products will become extinct.

Figure 7 shows the conventional route to market for a manufacturer of BAT. This often leaves the purchaser of the product to operate it without any direct input from the manufacturer. The result is that the purchaser has no direct or contractual access to the manufacturer's knowledge of how the product should be operated to deliver benefits to the purchaser.

**Figure 7. Traditional approach to procuring and operating building automation technology.**

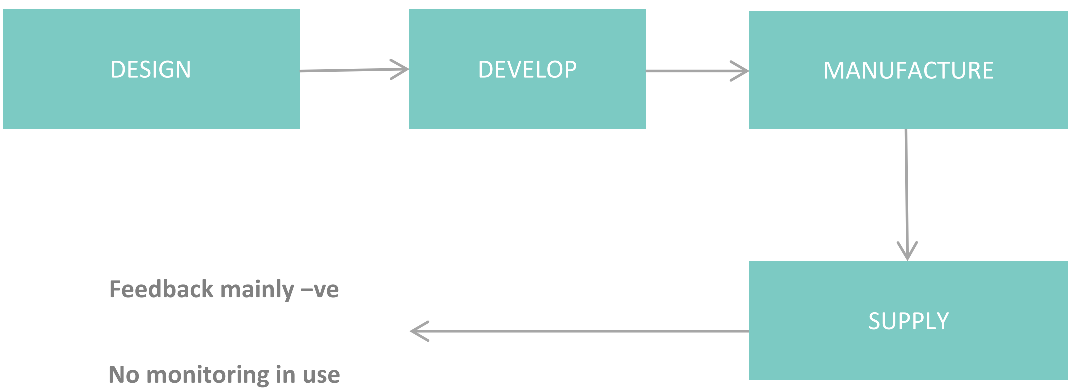
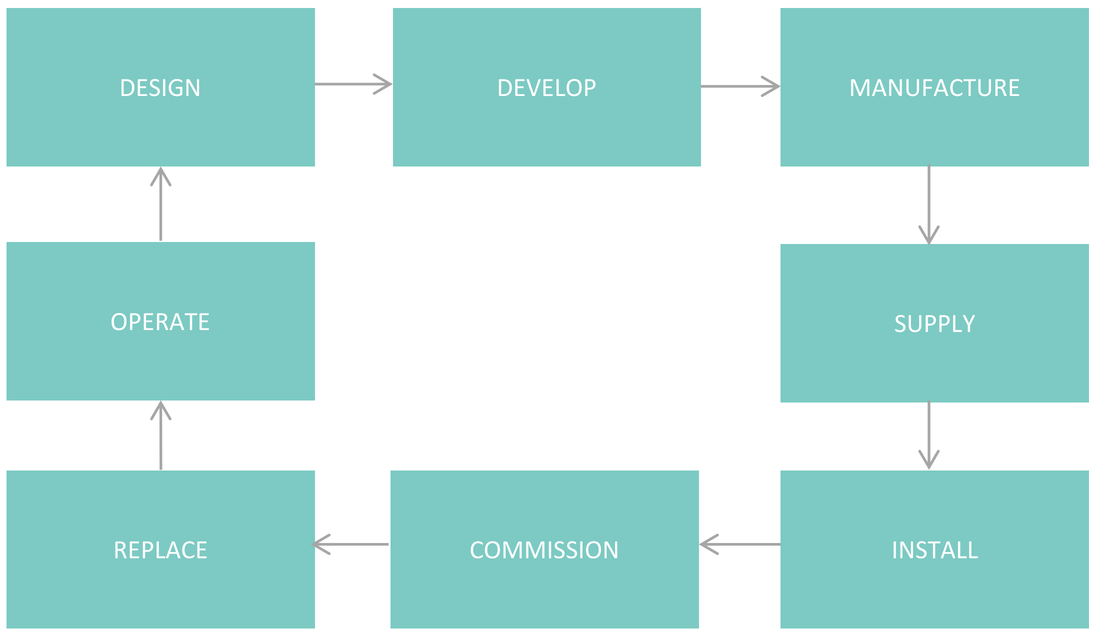


Figure 8 shows the lifetime product management route to market which enables the manufacturer of the product to deliver the benefits of its product to the end user and in the process receive an income stream over the life of the product that can be linked to its performance. With this process the manufacturer is encouraged to replace or enhance the product where this can improve performance and income.

**Figure 8. Lifetime product management approach to procuring and operating building automation technology.**




### *O&M*

BAT often fails to deliver its full potential as a result of inadequate O&M. Strategies and processes for O&M that enable the full benefits and expectations of BAT need to be realised.

#### *Performance-based service provision*

One of the main barriers to strategic operation of BSE and BAT is the traditional approach to specifying and procuring O&M services. Traditionally, property owners, occupiers and managers seek proposals for maintenance when what they really need is operation. Maintenance supports operation and only needs to be carried out to the level that ensures the desired operational requirements of the BSE and BAT are met. The emphasis must therefore be on operation and not on maintenance. BAT will only deliver at its best if it is operated to provide best value for occupier requirements. Maintenance alone is not enough.

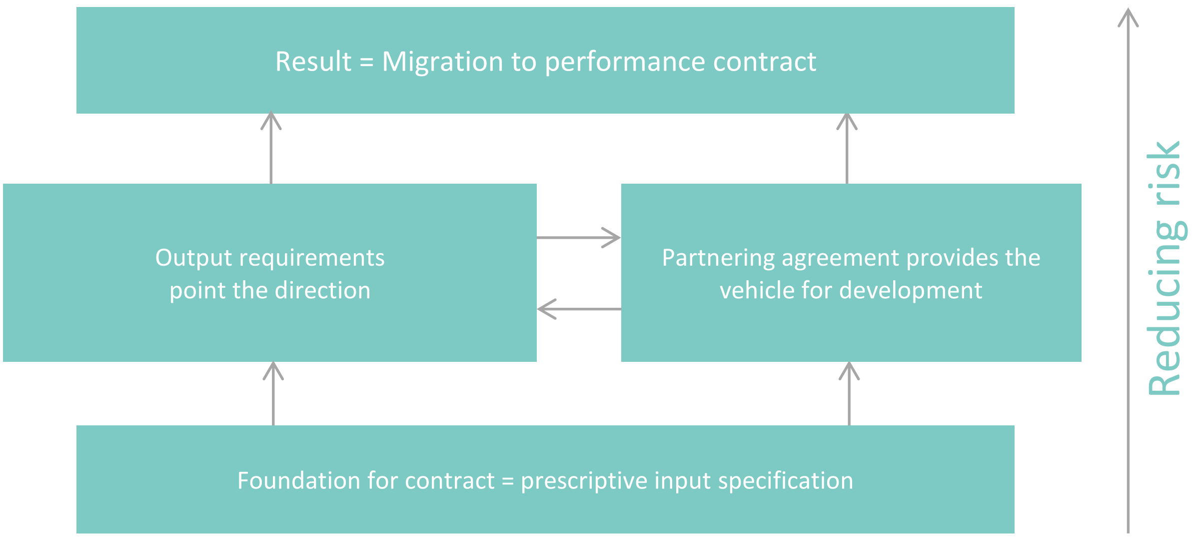
The problem is exacerbated by maintenance being procured by contractor proposals rather than in response to a specification. The selection of a contractor will be made following a comparison of contractor proposals and will usually be based on lowest cost. The contractor's proposals will often be based on assumptions of the client's requirements and therefore there will be little or no parity with regard to the proposals received.

Performance-based service provision ensures that operation is given the prominence it deserves and that the success of the service is measured by output rather than input. It can be introduced at any time in the building life cycle or throughout the life of an O&M contract by migration from a prescriptive input specification to an incentivised output performance specification. This process transfers the risk to the party that best understands it and hence reduces failures and costs. This is particularly applicable to BAT. Figure 9 outlines the migration from a prescriptive input service to an output-performance-based service.

### *Real-time energy monitoring*

The right energy-monitoring software is able to provide real-time and historic data on the energy consumption of both individual items of plant and equipment and a building as a whole, allowing

**Figure 9. Performance contract strategy.**




facilities managers to implement informed changes that will have measurable impact. EMOTR combines energy-management software with expert insight and includes:

- **e**nergy – gas, electricity, oil, solar, wind and water, with further analysis to identify dynamic and controllable loads. Other emission sources such as transportation, business travel and waste can be included. It is recommended to install metering on the main utilities, building services and data centres
- **m**onitoring – real-time consumption, carbon and cost (CCC) information via the internet
- **o**ptimising – limiting CCC to that needed for the occupier to deliver its business plan
- **t**argeting – setting and realising challenging but achievable targets while meeting the optimum requirements
- **r**eporting – regular reports on CCC trends with exception reports of deviations from targets and motivational information display dashboards.

### *Continuous commissioning*

Continuous commissioning is an operational strategy that continues commissioning beyond the original working settings of equipment and seeks to understand and optimise performance in use via an expert monitoring feedback and diagnostics process empowered with the authority to intervene to remedy significant failures when identified. Ideally it is part of a process, focused on operation, by which a building and its services are conceived, designed, constructed, commissioned, operated, maintained and decommissioned to provide the optimum of cost and value for the occupier. Research results demonstrate that the application of continuous commissioning to existing buildings delivers substantial operating-cost savings and greater occupant satisfaction. Specifying and operating BAT as part of a continuous commissioning process will go a long way to ensuring its full potential is realised. The process provides a strategic approach for incorporating and delivering all the human interface/operation considerations outlined in this section and enables buildings to deliver what is required of them in the most cost-effective and sustainable way without compromising quality. Its main characteristics are that it is:

- ongoing – the continuous commissioning principles are embedded in the client's overall operating strategy, enabling ongoing delivery with minimal external support
- holistic – continuous commissioning involves the whole organisation from top to bottom and addresses all factors affecting the project's success (technical, motivational and managerial).

# 4. Characterisation of the European building stock

## 4.1 Principal groupings of service sector buildings

An initial analytical task for this study was to gather data that appropriately characterise the European building stock in order to be able to assess the potential savings from the increased deployment and better use of BAT and BEMS. Following a review of the literature it was decided to categorise service sector (non-residential) buildings into the following principal groupings:

- offices
- retail outlets
- education establishments
- hotels and restaurants
- healthcare sector buildings
- other buildings.

While being simplifications of more complex distributions of building types, these groupings align with both distinctions made in EU policy documents (e.g.: EC 2010b, 2012a, 2012b) and available data on energy use and floor area (BPIE 2011; IEA 2012b; Urge-Vorsatz et al. 2012). Furthermore, this distinction captures many of the systematic relevant divisions in building energy services and the application of automated controls. An example of how building types would be grouped into these principal groupings in the UK is given in Table 1. Industrial buildings such as workshops, factories, laboratories, studios, commercial warehouses and storage units are not included in this analysis.

This grouping of service sector buildings into principal types also makes sense from the perspective of considering building energy use as there is sufficient homogeneity of function and usage to match to data on energy intensity, floor area distributions, renovation and new-build rates, adoption of building automated controls and costs.

## 4.2 Floor area and age of European buildings

Data on the floor area of buildings in Europe are drawn from the Building Performance Institute Europe (BPIE) building energy performance data hub at www.bpie.eu and match those used in a 2012 report for the Global Buildings Performance Network (Urge-Vorsatz et al. 2012). These data provide floor area estimates for the principal service sector building types defined in section 4.1 and for residential buildings, and, in the case of the GBPN report, projections of the growth in floor area by type to 2035.

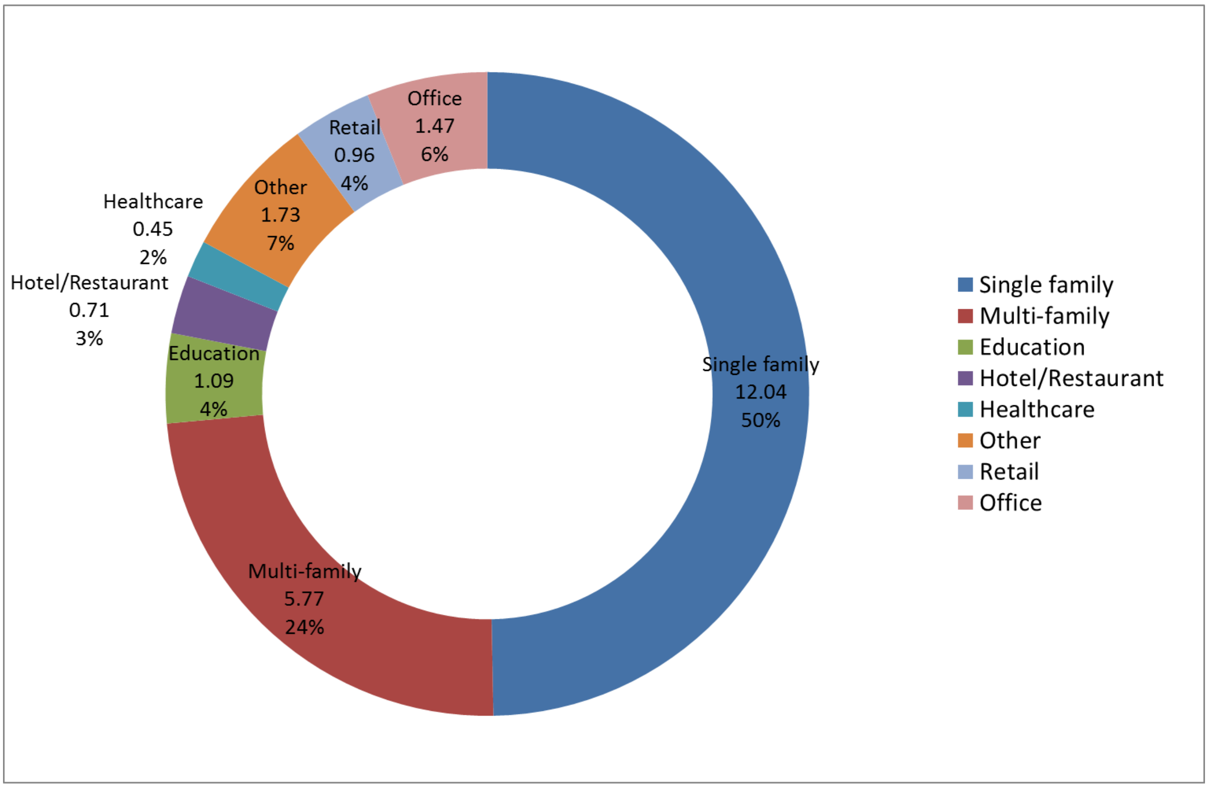
The estimated total floor area and share of building floor area by building type is shown in Figure 10. Service sector buildings account for 26% of all building floor area, although as their energy intensity is higher than that for residential buildings their share of energy use is higher (about 32% of final energy). The average floor area per building ($m^2$/building), by building type, is estimated as follows:

- office: 405 $m^2$
- retail: 218 $m^2$
- education: 5 063 $m^2$hotel/restaurant: 310 $m^2$
- healthcare: 1 084 $m^2$
- other: 2 995 $m^2$.

### Table 1. Grouping of service sector buildings by type within the UK.

| Principal type | Intermediate type | Sub-type |
|---|---|---|
| Offices | Government estate | Central government office |
| | Public offices | Local government office |
| | Commercial offices | Commercial offices of all kinds |
| Retail | Retail | Small or general shop |
| | | Market stall |
| | | Large shop |
| | | Supermarket |
| | | Commercial services |
| | | Bank or building society |
| | | Post Office |
| | | Hairdressing/beauty salon |
| | | Laundrette |
| | | Dry cleaner |
| Education | Schools | Pre-school facility |
| | | State school |
| | | Private school |
| | Further and higher education | Further, higher education |
| | | University |
| | | Adult education centre |
| Hotels and restaurants | Hotels, inns and restaurants | Takeaway |
| | | Restaurant |
| | | Public house |
| | | Hotel or motel |
| | | Boarding/guesthouse |
| | | Holiday let |
| Healthcare | Healthcare | Surgery or clinic |
| | | Hospital |
| | | Care |
| Other | Sports | Leisure centre |
| | | Swimming pool |
| | | Pavilion/sports clubhouse |
| | Heritage and entertainment | Collection and display |
| | | Library |
| | | Entertainment hall |
| | | Cinema |
| | | Bingo hall |
| | | Snooker club |
| | | Night club, disco |
| | | Amusement arcade |
| | Transport and communications | Vehicle services |
| | | Parking |
| | | Bus depot |
| | | Railway premise |
| | | Dock, wharf |
| | Miscellaneous | Community meeting place |
| | | Emergency services |
| | | Police station |

**Figure 10. Projected distribution of European service sector and residential building floor area (billion m²) by building type in 2013.**



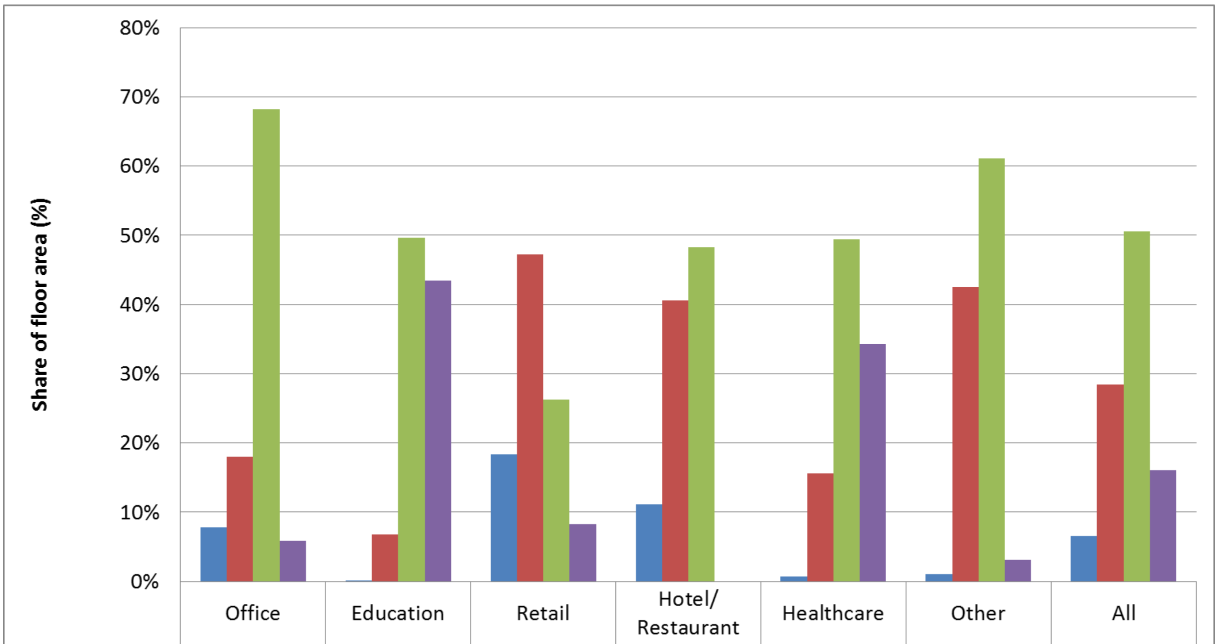

The estimated distribution in 2013 of the service-area stock building floor area by size is shown in Figure 11.

The age distribution of buildings is relevant when considering the likely levels of insulation and, to a slightly lesser extent, vintage and penetration of building energy services equipment. The BPIE data set includes data on building age distributions for most European countries, but this is complemented by energy-intensity data (distributed by age) for only a small number of countries (and only smaller countries among these). More commonly it includes data on the average U-values as a function of building age, from which heating loads can be inferred for equal service loads; however, in practice, more modern buildings will also often tend to be correlated with the presence of greater thermal comfort and air-quality management and higher intensity of installed equipment, which can serve to cancel out the energy savings expected from better-insulated fabrics and more modern equipment. Given this and the inadequacy of the available data, the analysis presented in section 5 averages the treated buildings as a function of age, although it does take account of the estimated penetration and vintage of BAT/BEMS as a function of time.

## 4.3 Distribution of buildings by European country

Information on the distribution of service sector buildings by European nation is also available from the same BPIE data set mentioned in section 4.2 and was used to derive expected cost-benefits of BAT/BEMS as a function of systematic differences in energy prices (IEA 2012a), climate and current penetration levels of BAT/BEMS.

**Figure 11. Assumed distribution of European service sector building floor area (m²) by building type in 2013 (values show the proportion of stock floor area by floor area range).**




| | Office | Education | Retail | Hotel/ Restaurant | Healthcare | Other | All |
|---|---|---|---|---|---|---|---|
| 0-100 | 7.8% | 0.1% | 18.4% | 11.2% | 0.7% | 1.1% | 6.5% |
| 100-1000 | 18.0% | 6.8% | 47.2% | 40.5% | 15.6% | 42.6% | 28.5% |
| 1000-10,000 | 68.2% | 49.6% | 26.2% | 48.3% | 49.4% | 61.1% | 50.6% |
| Over 10,000 | 5.9% | 43.5% | 8.2% | 0.0% | 34.3% | 3.1% | 16.0% |

## 4.4 Distribution of building energy consumption by end use

Figure 12 shows the estimated breakdown of European service sector building final energy consumption by principal end use in 2013, from which it is clear that space heating is dominant, followed by water heating. The essentially purely electric end uses of lighting, cooling/ventilation and other electric equipment account for 29% of final energy use, but when electric space and water heating is considered electricity accounts for 44% of final energy use and a much greater proportion of primary energy use. The estimated distribution of residential building final energy consumption by end use is shown in Figure 13. Space heating is even more dominant in residential buildings, although if the data were to be expressed in primary energy terms the shares taken by the purely electric end uses would become much greater.

## 4.5 Penetration of BAT/BEMS and BAT/HEMS in European buildings

### *Service sector buildings*

Effectively, all service sector buildings in the EU have some kind of BAT installed; the baseline will usually be at least to have thermostats, time switches and, in many countries, optimum start control. These measures already save a considerable amount of energy in EU buildings, and thus the savings computed and presented in section 5 are compared to this BAT baseline.

Penetration of BMS (as distinct from BEMS) is probably about 90% of the larger EU public and commercial buildings but is very low for smaller public and commercial buildings; however, only

**Figure 12. Estimated distribution of European service sector building final annual energy consumption by end use in 2013 (Mtoe).**

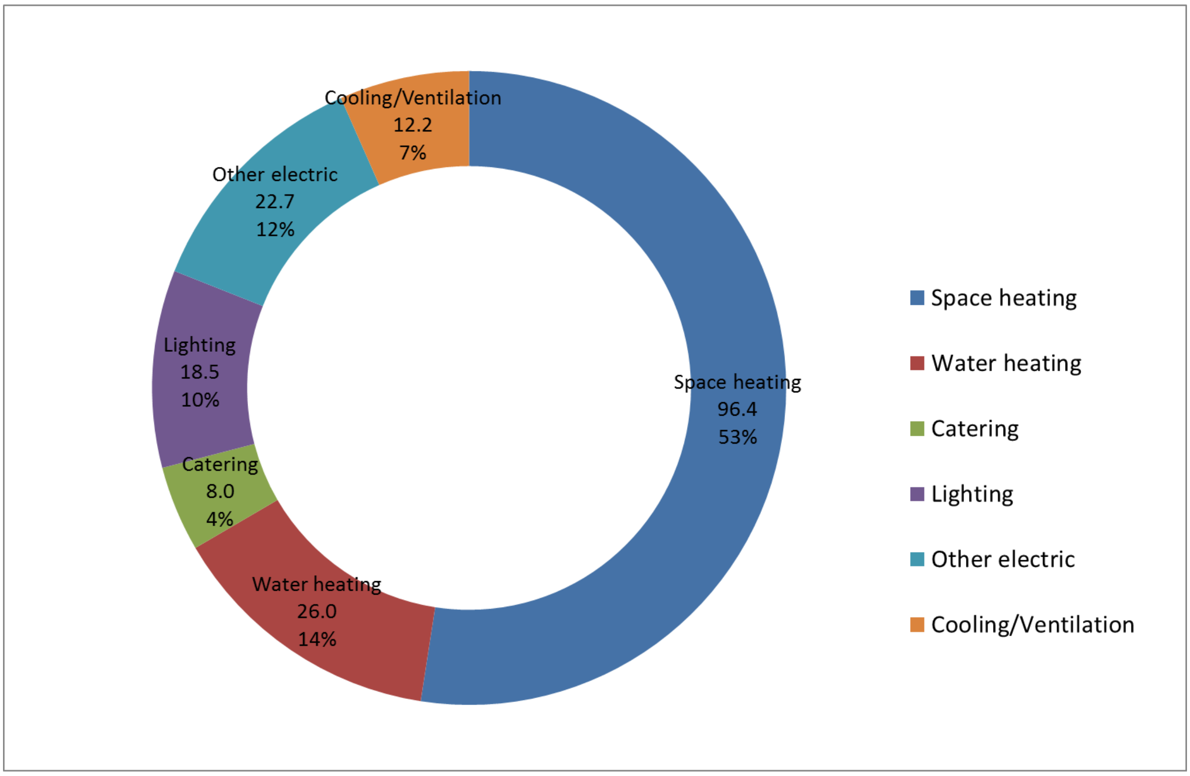



**Figure 13. Estimated distribution of European residential building final annual energy consumption by end use in 2013 (Mtoe).**

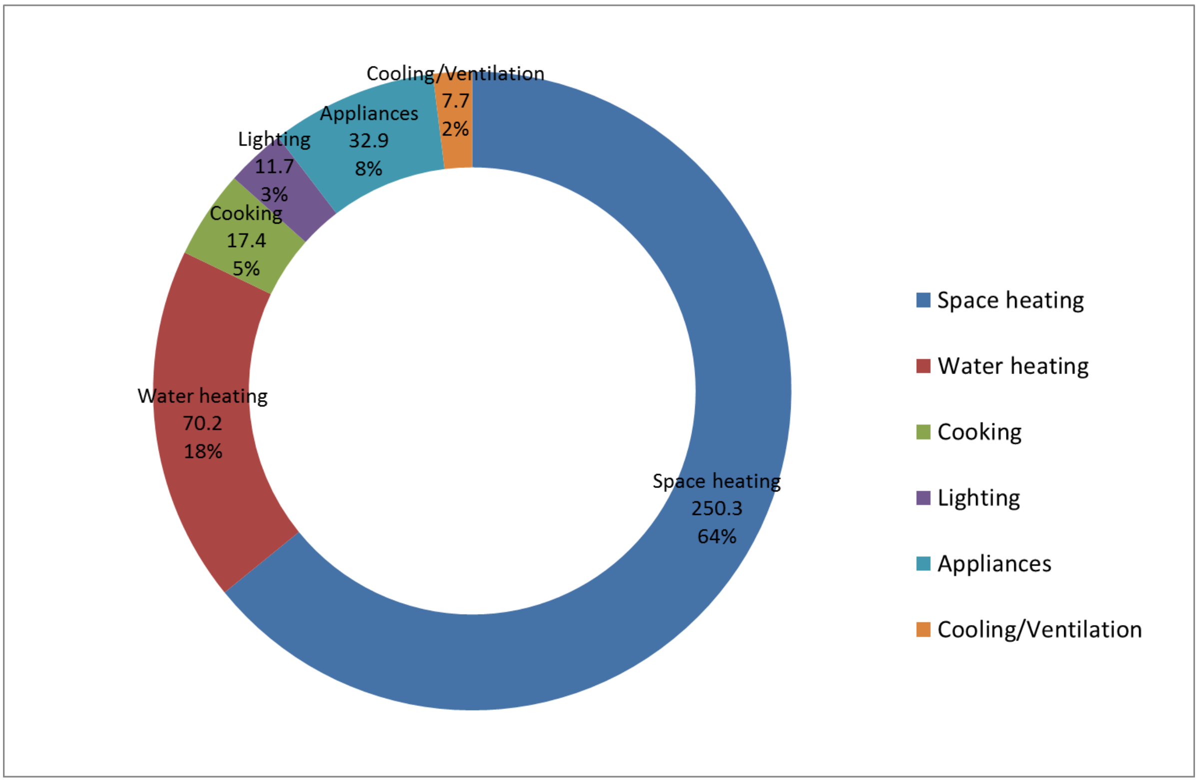


**Table 2. Estimated building automation technology (BAT)/building energy management systems (BEMS) sales by service sector building type in Europe in 2010.**

| | Education | Hotels & restaurants | Hospitals | Retail | Offices | Other | All |
|---|---|---|---|---|---|---|---|
| Share of EU27 service sector floor area | 17% | 11% | 7% | 15% | 23% | 27% | 100% |
| Total floor area (million $m^2$) | 1 001 | 648 | 412 | 883 | 1 354 | 1 590 | 5 889 |
| BAT/BEMS sales (€/$m^2$) | 0.57 | 0.74 | 1.41 | 0.41 | 0.59 | 0.74 | 0.67 |
| Share of floor area fitted with BAT/BEMs per year | 1.6% | 2.6% | 4.9% | 1.7% | 2.2% | 2.6% | 2.4% |
| Floor area fitted with BAT/BEMS per year (million $m^2$) | 16.1 | 16.7 | 20.2 | 15.0 | 29.6 | 41.0 | 139 |
| Cost to procure, install and commission BAT/BEMS (€/$m^2$) | 35.20 | 28.70 | 28.70 | 24.00 | 27.00 | 28.70 | 28.70 |
| Average energy use (kWh/$m^2$) | 278 | 524 | 622 | 288 | 325 | 250 | 334 |

about 50% of the installed BMS have more than an elementary energy management capability. Overall, only about 26% of total public and commercial building floor area in the EU is thought to have BEMS operational capacity installed (as opposed to BMS operational capacity, which is higher). Note, however, that data on the actual penetration of BAT/BMS/BEMS in the EU building stock are scarce and the values used here are based on expert consensus combined with an analysis of BEMS/BMS/BAT sales by market and building type.

From this it can be concluded that across Europe the following relationship provides a reasonable estimate of the sales in a given economy:

$$\text{BAT/BEMS-Sales}_{\text{Capita}} = 0.9095 \cdot \exp(0.0876 \cdot \text{GDP}_{\text{Capita}})$$

where:

- $\text{BAT/BEMS-Sales}_{\text{Capita}}$ is the value (in Euro) of per capita sales of BAT/BEMS in service sector buildings in a given European country
- $\text{GDP}_{\text{Capita}}$ is the average gross domestic product per capita (in Euro) of the European country in question.

While this provides a reasonable indicator of BAT/BEMS sales value, on average per capita sales in some economies are thought to be 20–30% above the values predicted by this formula (Eastern Europe, the UK and the Nordic countries) and sales in some are thought to be 10–35% below it (France, Italy, Spain and the Benelux countries), yet sales in Germany are about 80% above it. Combining this with Germany's large population and high per capita GDP indicates that it has a disproportionately high share of the European BAT market and therefore a higher penetration of BAT/BEMS within its buildings than in other European economies.

Nor is penetration of BAT/BEMS evenly distributed across the building stock by building type. Sales are roughly twice as high per unit area for hospitals, which tend to have high energy intensity, as they are for the stock average (Table 2).

There are a number of drivers of future market penetration of BAT/BEMS in European service sector buildings, including:

- new-build, refurbishment/renovation and refitting rates
- technological innovation and greater value added in service offerings

**Table 3. Estimated building automation technology (BAT)/home energy management systems (HEMS) sales by residential sector building type in Europe in 2013.**

| | Single-family residences | Multi-family residences |
|---|---|---|
| Share of EU27 residential floor area | 67.6% | 32.4% |
| Total floor area (million $m^2$) | 12 036 | 5 771 |
| BAT only sales (€/$m^2$) | 0.21 | 0.25 |
| BAT/HEMS sales (€/$m^2$) | 0.18 | 0.01 |
| Share of floor area fitted with BAT per year | 3.6% | 4.9% |
| Share of floor area fitted with BAT/HEMS per year | 1.4% | 0.1% |
| Floor area fitted with BAT only per year (million $m^2$) | 433 | 283 |
| Floor area fitted with BAT/HEMS per year (million $m^2$) | 169 | 6 |
| Cost to procure, install and commission BAT only (€/$m^2$) | 5.94 | 5.00 |
| Cost to procure, install and commission BAT/HEMS (€/$m^2$) | 12.50 | 12.00 |

- energy prices
- increasing awareness of energy costs and carbon footprints
- regulations
- other policy incentives.

While the traditional drivers linked to the renewal/replacement cycles of buildings are strongly tied to economic growth and are hence currently depressed (especially new build, less so renovation), the strengthening trends in the remaining drivers have tended to more than overcome this in the last few years and sales have continued to grow.

### *Residential buildings*

The large majority of residential buildings in Europe have some kind of BAT installed, even if as simple as a timer-controlled thermostat for the heating system. A much smaller proportion have modern HEMS coupled to intelligent and demand-responsive controls. The national implementation of building codes, driven by the EPBD (EC 2002, 2010), are increasingly becoming key drivers of the level of functionality and sophistication of controls that are installed in new or retrofit buildings, but even these fall short of requiring HEMS to be installed. A more typical requirement under current building regulations would be to specify the use of (i) thermostatic radiator valves (TRVs) on all heat emitters, (ii) programmers and (iii) room zoning valves.

Aggregate market information on the sales volumes of BAT in residential buildings is relatively scarce and estimates of the HEMS market also vary significantly, especially as it is predicted in many quarters to grow quite rapidly from a low base. There are very significant differences in market volumes and penetration rates for HEMS depending on region, such that per capita sales in Western European markets are thought to be two orders of magnitude higher than in Eastern European markets, although this also reflects the very low adoption rate across Europe as a whole and the nascent state of the market. Based on analysis of a variety of sources and expert views, the estimated BAT and BAT/HEMS sales data presented in Table 3 were derived and used as the starting point of the energy modelling analysis (see section 5) for the residential sector.

# 5. Overall energy savings potential estimates for EU building stock from greater deployment and better operation of BAT

## 5.1 Scenarios considered

This section derives estimates for the potential for savings from increased deployment and better operation of BAT/BEMS across the EU building stock. Three scenarios were developed:

- **Reference Scenario**, which assumes a continuation of current trends regarding the adoption and installation of BAT/BEMS in the service sector and BAT/HEMS in the residential sector, with no significant improvement in installation and management procedures
- **Optimal Scenario**, which assumes that there is an optimal level of installation and operation of BAT/BEMS or BAT/HEMS from a user cost-effectiveness perspective[4]
- **Recommended Action Scenario**, which assumes that the recommended actions outlined in section 7 are followed and that BAT/BEMS and BAT/HEMS are procured, installed and operated accordingly.

These scenarios were then simulated for the European building stock in a purpose-built building energy stock model to estimate the expected impacts on building energy use and costs. Projections were generated by principal energy end use, building type and fuel from 2013 to 2035. In broad terms, the Reference Scenario is aligned with the European building component of the International Energy Agency's *World Energy Outlook 2012* Current Policies Scenario (IEA 2012b) in order to ensure consistency and comparability of energy-supply assumptions and prices. The other two scenarios are higher penetration of BAT/BEMS/HEMS and better deployment derivatives from this Reference Scenario.

## 5.2 Estimated savings per building type and projected BAT penetration

### *Service sector buildings*

Currently, BEMS are probably saving an average of about 10% of building HVAC energy consumption in service sector buildings where they are installed above the BAT baseline, i.e. about 2.6% of EU building HVAC energy consumption as a whole (= 0.26*10) compared to the BAT baseline. The share of building area with BEMS installed is increasing and is expected to continue to increase without additional measures; it is assumed to reach 35% of service sector floor area by 2023 and 45% by 2033 without additional measures to stimulate the market (Figure 14).

If BAT/BEMS were properly designed, installed, commissioned and operated, making using of all economically viable control-related energy-savings opportunities, the average savings per commercial/public building would be of the order of 37%, i.e. 27% higher in absolute terms than is currently achieved with BAT/BEMS. There are a number of reasons for this, as partially set out below, but inadequate operation is the main reason why existing BEMS do not save more energy than under the Reference Scenario. Thus there is an unexploited HVAC and hot water energy savings potential of about 34% (= 0.26*27 + 0.74*37).

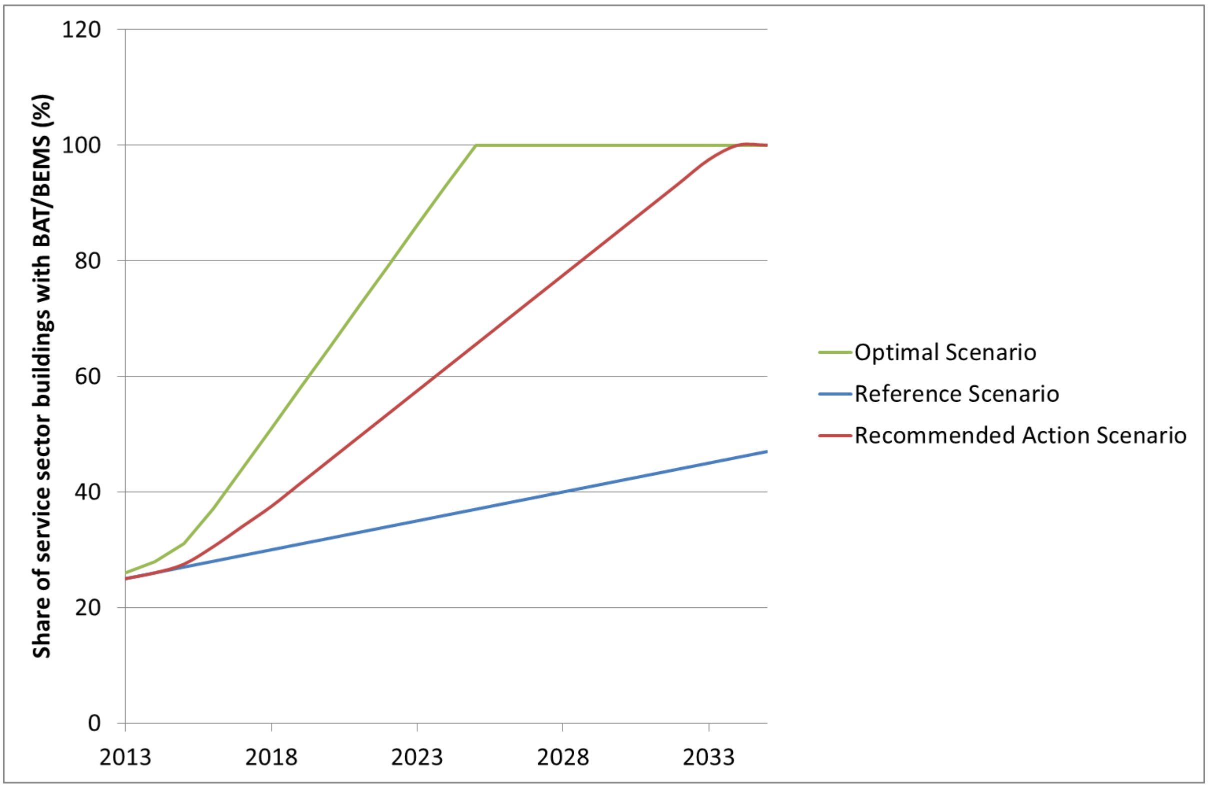
In the case of lighting, the overall savings potential from further deployment of optimised controls alone is probably about 25% of building lighting electricity demand, but a wide range of figures is seen in the literature.

Savings from the optimum application of BAT/BEMS in other end uses are usually less significant.

[4] i.e. that If BAT/BEMS or BAT/HEMS were properly designed, installed, commissioned and operated, making using of all economically viable control-related energy-savings opportunities

Experience has shown that the energy savings to be expected from the use of BAT/BEMS is highly dependent on a number of real-world concerns. For example, BEMS, when operated as simple plug-and-

**Figure 14. Assumed penetration of modern building automation technology (BAT)/building energy management systems (BEMS) as a share of European service sector building floor area (m²) from 2013 to 2035.**




-play tools by typical building management operatives, will produce quite different levels of savings than when operated by an expert user. The whole nature of the way BAT/BEMS are installed and commissioned, combined with the quality of the user interface, user training, and support, monitoring and evaluation system including continuous commissioning, has a very large impact on the outcomes to be expected. Case studies of actual BAT/BEMS projects are presented in Appendix B.

The savings potentials derived from the use of BAT/BEMS in the base buildings for the three scenarios were applied across the European building stock as a whole to produce time-dynamic estimates of energy savings potentials.

Under the Reference Scenario, penetration of BAT/BEMS rises by roughly 1% per year from 26% of the service sector floor area to 48% by 2035, which is in line with current market trends. The net energy savings per installation are assumed to be 10% for space heating, water heating, cooling/ventilation and lighting. Individual buildings will achieve much greater savings than this, but these values reflect the fact that there is currently a spectrum to savings and that in the worst cases building energy use can even increase owing to improper operation of complex control systems. The 10% savings reflect the aggregate benefit expected from current BAT/BEMS with the spectrum of installation, commissioning and operation behaviour currently seen across the EU building stock.

Under the Optimal Scenario, penetration of BAT/BEMS ramps up at a much faster pace and reaches 65% by 2020 and 100% by 2025 (see Figure 14). This reflects that the analysis of cost-benefits of

BAT/BEMS shows that they are cost-effective for all service sector buildings regardless of national energy prices, usage and climatic factors, provided they are correctly installed, commissioned and operated. This idealised scenario assumes there are no barriers to greater installation than the rapidity with which industry could respond to client demand and equally assumes a fully rational market. The net energy savings per installation are assumed to be 37% for space heating, water heating and cooling/ventilation, and 25% for lighting. It is instructive to contrast these energy savings estimates with those that would be derived by applying the energy efficiency factors indicated in the EN 15232: 2012 standard. When weighted by building type and energy service (heating/cooling, hot water and other electrical end uses) to represent the average energy use per floor area of the EU service sector building stock the savings potential in moving from a class D to class A BAT/BEMS is 49%, whereas the savings potential in moving from a class C to class A BAT/BEMS is 26%. Class C is considered to be the reference case for new installations whereas much of the existing stock will have poorer class D controls and building automation technology configurations, thus the savings per installation assumed in the Optimal Scenario is consistent with the potentials expressed in EN 15232.

Under the Recommended Action Scenario, penetration of BAT/BEMS rises more gently than under the Optimal Scenario, reaching 50% by 2021, 66% by 2025 and 90% by 2031 (see Figure 14). This slower rate of adoption reflects that even with the implementation of a strong policy mix supported by sustained programmatic actions, the rate of ramp-up and adoption of any technology is constrained by a blend of capacity limitations and market barriers. Equally, the average net energy savings per installation are assumed to be lower than under the Optimal Scenario, at 27% for space heating, water heating and cooling/ventilation and 20% for lighting.

### *Residential buildings*

As with the service sector, penetration of automated building energy control technology is already high in the residential sector, but is low if intelligent control is considered. There are no systematic surveys of the stock of energy control technology in use in European households and so assumptions have had to be made on the basis of the analysis of more limited data sets and expert judgements. From this it is estimated that, on average, proper installation and use of the better types of BAT/HEMS will save 25% of heating and hot water energy compared to a typical controls arrangement that satisfies current requirements in building codes and will save over 30% compared to the average default installed control systems in the building stock. These assumptions are used for the Optimal Scenario.

It is instructive to contrast these energy savings estimates with those that would be derived by applying the energy efficiency factors indicated in the EN 15232: 2012 standard. When weighted by building type and energy service (heating/cooling, hot water and other electrical end uses) to represent the average energy use per floor area of the EU service sector building stock the savings potential in moving from a class D to class A BAT/BEMS is 65%, whereas the savings potential in moving from a class C to class A BAT/BEMS is 34%. Class C is considered to be the reference case for new installations so the Optimal Scenario is consistent with moving from a class C to a class A BAT/BEMS configuration under EN 15232.

Under the Recommended Action Scenario, however, it is assumed that the average typical savings experienced are slightly less than two-thirds of these values per installation owing to failures in specification, installation and operation that are difficult to avoid. The savings assumptions for lighting and smart appliances are much more modest (less than 5%) as there is less functionality in the existing equipment and less robust information on which to base the estimated impact. In general it is assumed that any savings in lighting/appliances that may be expected from the deployment of BAT/HEMS over the scenario period will offset the additional electricity consumption of the equipment itself and therefore are net neutral. The projected penetration of BAT/HEMS in the residential sector under the three scenarios is shown in Figure 15.

## 5.3 Expected energy savings across the European building stock

### *Service sector buildings*

The expected total annual service sector buildings energy savings under the Optimal Scenario and the Recommended Action Scenario compared to the Reference Scenario are shown in Figures 16 and 17, respectively. As the Reference Scenario already includes a default increase in deployment of BAT/BEMS, these scenarios show the additional savings potential that remains to be realised above and beyond what is expected with current trends and practice. In the case of the Recommended Actions Scenario they indicate what could be achieved from a robust set of policy measures that are carefully implemented.

- Under the Optimal Scenario, annual energy savings peak in 2035 at 49.7 Mtoe, which is 20.3% of all EU service sector building energy consumption.
- Under the Recommended Action Scenario, annual energy savings peak in 2035 at 40.3 Mtoe, which is 16.5% of all EU service sector building energy consumption.

**Figure 15. Assumed penetration of modern building automation technology (BAT)/home energy management systems (HEMS) as a share of European residential building floor area ($m^2$) from 2013 to 2035.**

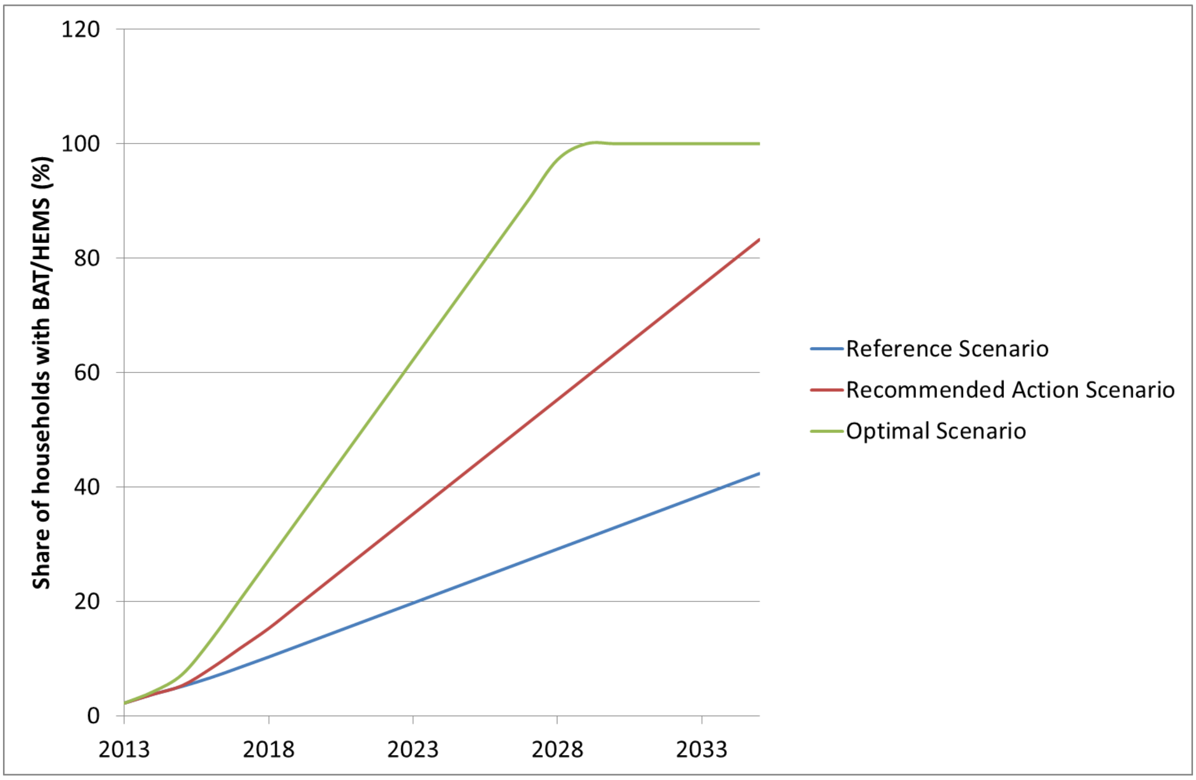


**Figure 16. Service sector building additional energy savings under the Optimal Scenario compared with the Reference Scenario from 2013 to 2035.**

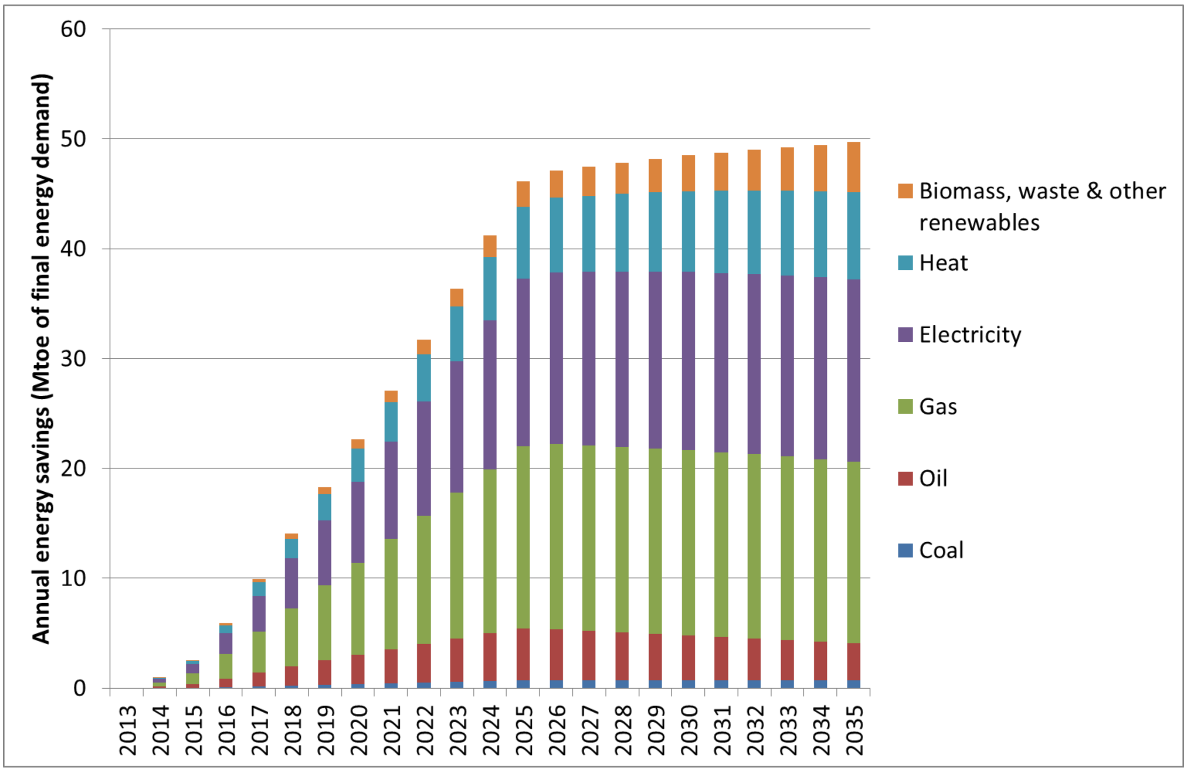
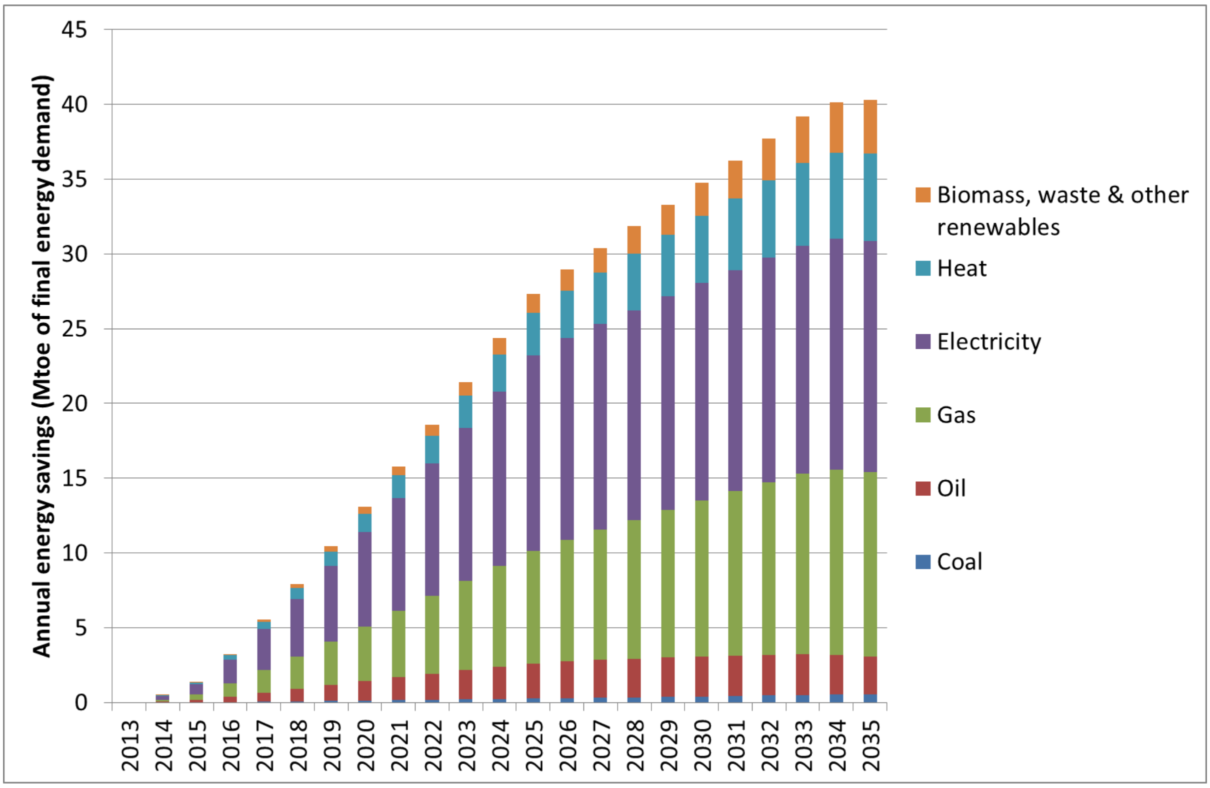



**Figure 17. Service sector building additional energy savings under the Recommended Action Scenario compared with the Reference Scenario from 2013 to 2035.**



Cumulative savings in final energy consumption from 2013 to 2035 under the Optimal Scenario are 742 Mtoe, whereas under the Recommended Action Scenario they are 502 Mtoe. These are 14.8% and 10.0%, respectively, of the cumulative residential building energy consumption under the Reference Scenario from 2013 to 2030.

### *Residential buildings*

The expected total annual residential buildings energy savings under the Optimal Scenario and the Recommended Action Scenario compared to the Reference Scenario are shown in Figures 18 and 19, respectively. As the Reference Scenario already includes a default increase in deployment of BAT/HEMS, these scenarios show the additional savings potential that remains to be realised above and beyond what is expected with current trends and practice.

- Under the Optimal Scenario, annual energy savings peak in 2029 at 98.1 Mtoe, which is 23.4% of all European residential building energy consumption.
- Under the Recommended Action Scenario, annual energy savings peak in 2035 at 49.0 Mtoe, which is 11.3% of all European residential building energy consumption.

Cumulative savings in final energy consumption from 2013 to 2030 under the Optimal Scenario are 1 357 Mtoe, whereas under the Recommended Action Scenario they are 498 Mtoe. These are 12.8% and 4.7%, respectively, of the cumulative residential building energy consumption under the Reference Scenario from 2013 to 2030.

**Figure 18. Residential building additional energy savings under the Optimal Scenario compared with the Reference Scenario from 2013 to 2035.**

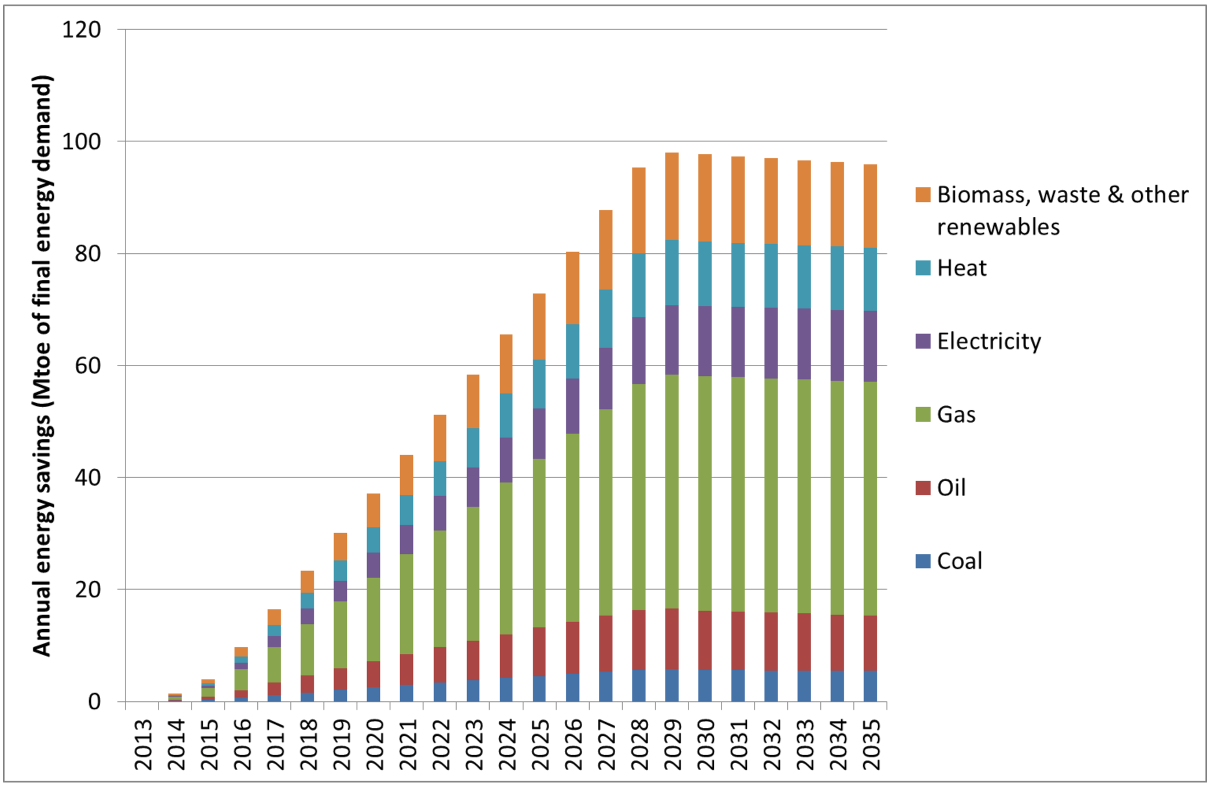
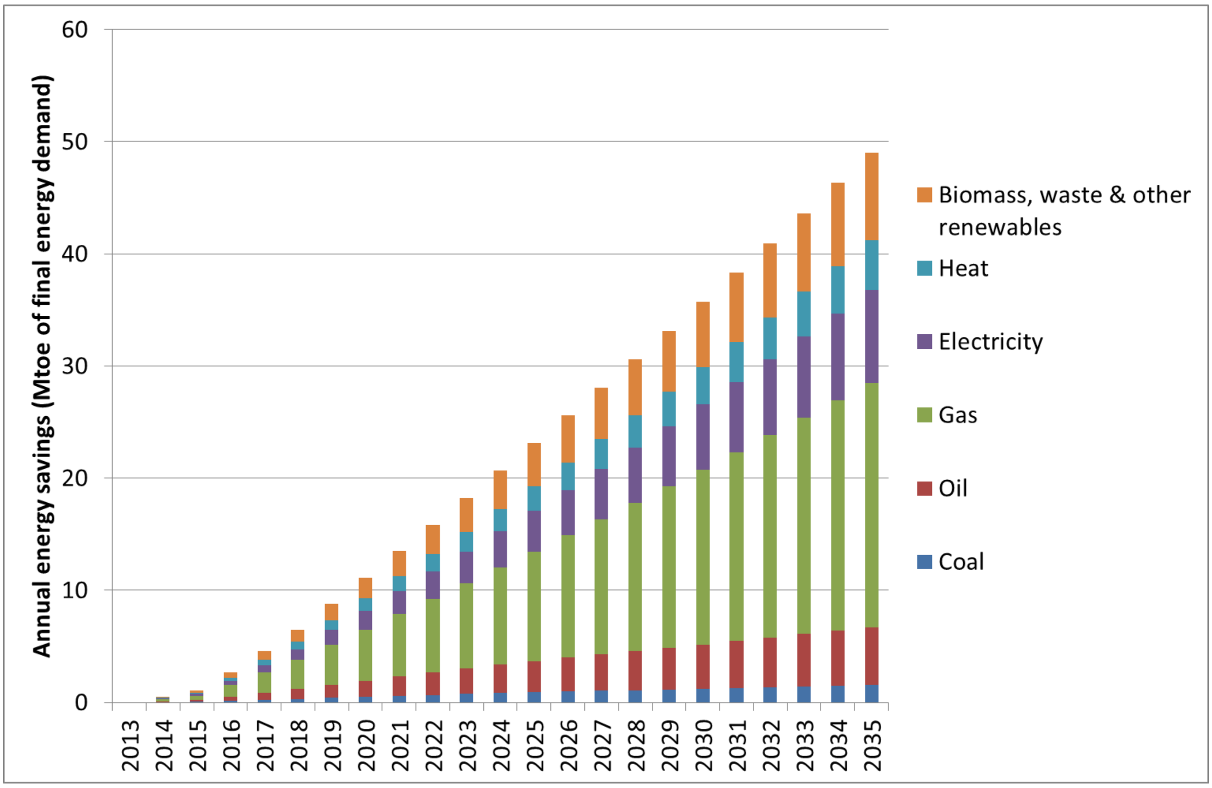


**Figure 19. Residential building additional energy savings under the Recommended Action Scenario compared with the Reference Scenario from 2013 to 2035.**




## 5.4 Estimates of investment needs and bill savings

### *Service sector buildings*

On average it is estimated that the cost to procure, install and commission BAT/BEMS is €28.70/$m^2$ of service sector building floor area. These values are derived from a blend of professional literature review, analysis of product pricing and in-field experience. The mean cost per unit area varies as a function of building type (see Table 2). It also varies as a function of building size, being higher for smaller buildings than larger ones owing to economies of scale.

The associated additional investments compared to the Reference Scenario scaled up over the entire EU service sector building stock are shown in Figure 20. Cumulative total additional investments from 2013 to 2035 are €44.0 billion under the Optimal Scenario and €40.8 billion under the Recommended Action Scenario; however, although the totals are similar, the profile of incremental investment is much higher initially for the former than for the latter. Under the Optimal Scenario, incremental investments peak at €4.6 billion, before dropping sharply, whereas in the Recommended Action Scenario they peak at €2.5 billion, but this order of incremental investment is sustained for much longer. In both cases, incremental investments drop away to zero compared to the Reference Scenario as maximum penetration is reached and the market becomes a replacement market.

The value of avoided energy bills attributable to this investment is shown in Figure 21. Under the Optimal Scenario, savings in annual energy bills rise to €51 billion in 2025 and then rise more slowly to €56 billion at the end of the scenario period as the savings from BAT/BEMS under the Reference

**Figure 20. Investments in building automation technology/building energy management systems in European service sector buildings under the Recommended Action and Optimal Scenarios from 2013 to 2035.**

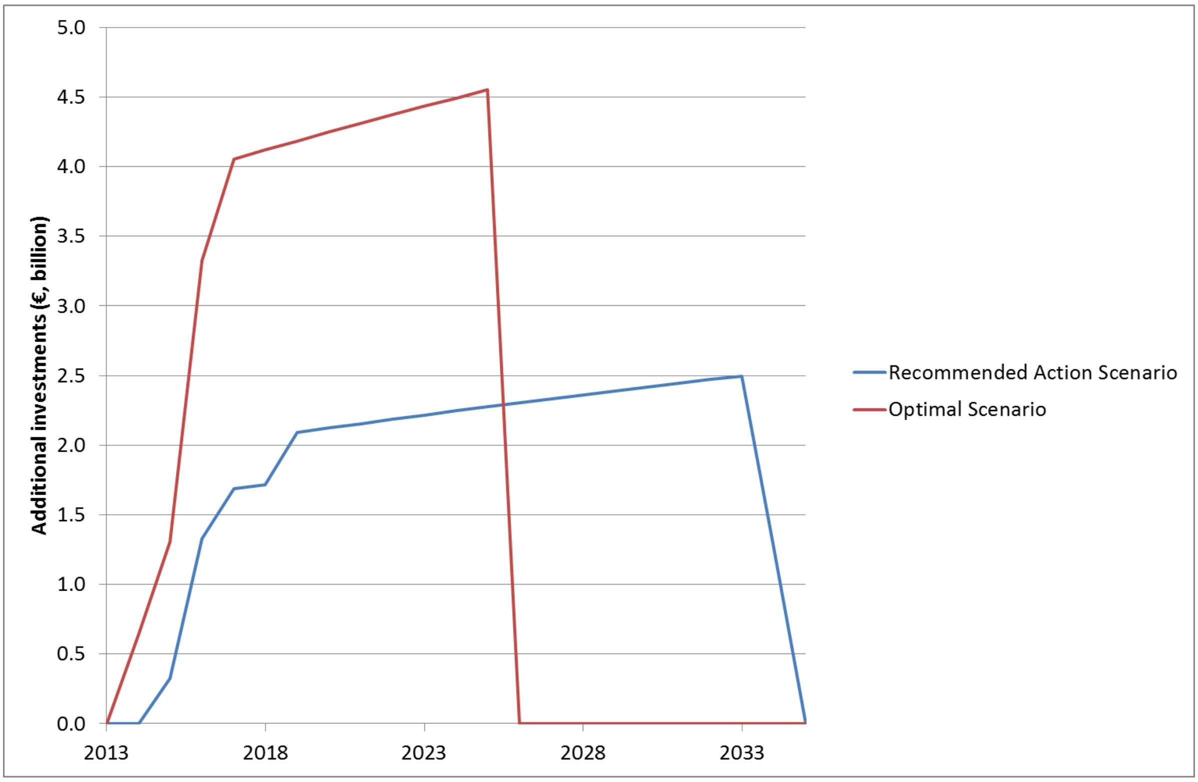
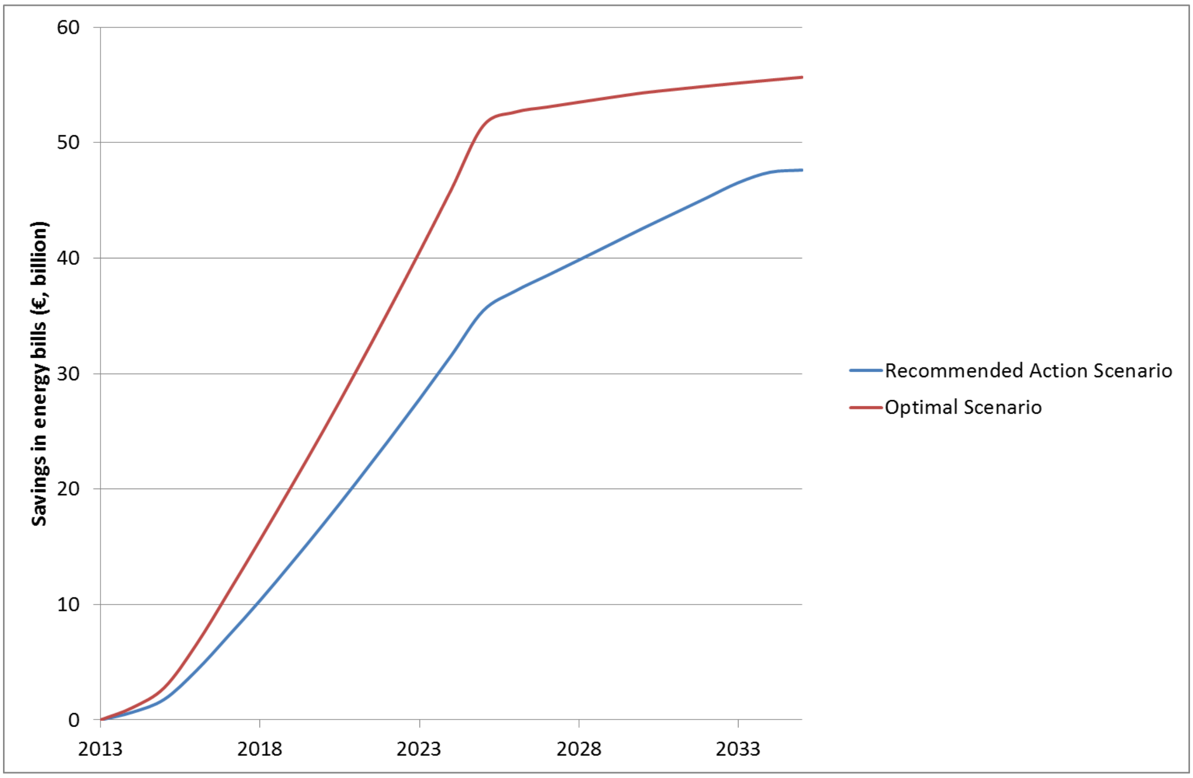



**Figure 21. Savings in European service sector building energy bills under the Recommended Action and Optimal Scenarios from 2013 to 2035.**



Scenario begin to catch up. In the Recommended Action Scenario, annual energy bill savings peak at just under €48 billion at the end of the scenario period. Cumulative total additional energy bill savings from 2013 to 2035 are €829 billion under the Optimal Scenario and €624 billion under the Recommended Action Scenario. These are 18.8 and 15.3 times, respectively, as great as the magnitude of the additional investment.

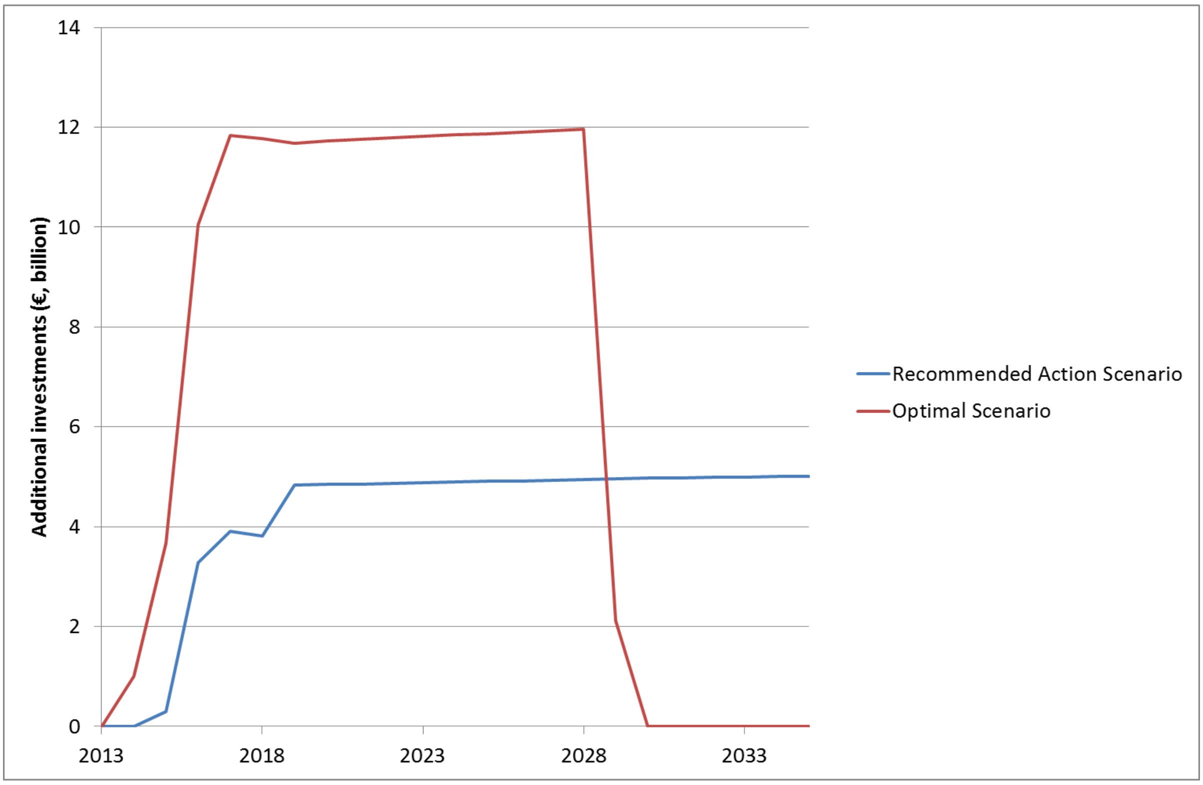
The average payback periods are very short at only 1.5 years, and despite variation across building types and economies owing to variations in energy prices and energy consumption, the investment in BAT/BEMS is always cost-effective providing the design, installation, commissioning and operation is appropriate for the building type considered.

### *Residential buildings*

On average it is estimated that the cost to procure, install and commission BAT/HEMS is €12.30/$m^2$ of residential building floor area. The mean cost per unit area varies as a function of building type (see Table 3). It also varies as a function of building size, being slightly higher for smaller buildings than larger ones owing to economies of scale. As was the case for the service sector, these values are derived from a blend of professional literature review, analysis of product pricing and in-field experience.

The associated additional investments compared to the Reference Scenario scaled up over the entire European residential building stock are shown in Figure 22. Cumulative total additional investments from 2013 to 2035 are €159 billion under the Optimal Scenario and €95 billion under the Recommended Action Scenario. Under the Optimal Scenario, incremental investments peak at between €11 billion and €12 billion from 2017 to 2028, before dropping sharply, whereas in the

**Figure 22. Investments in building automation technology/building energy management systems in European residential buildings under the Recommended Action and Optimal Scenarios from 2013 to 2035.**

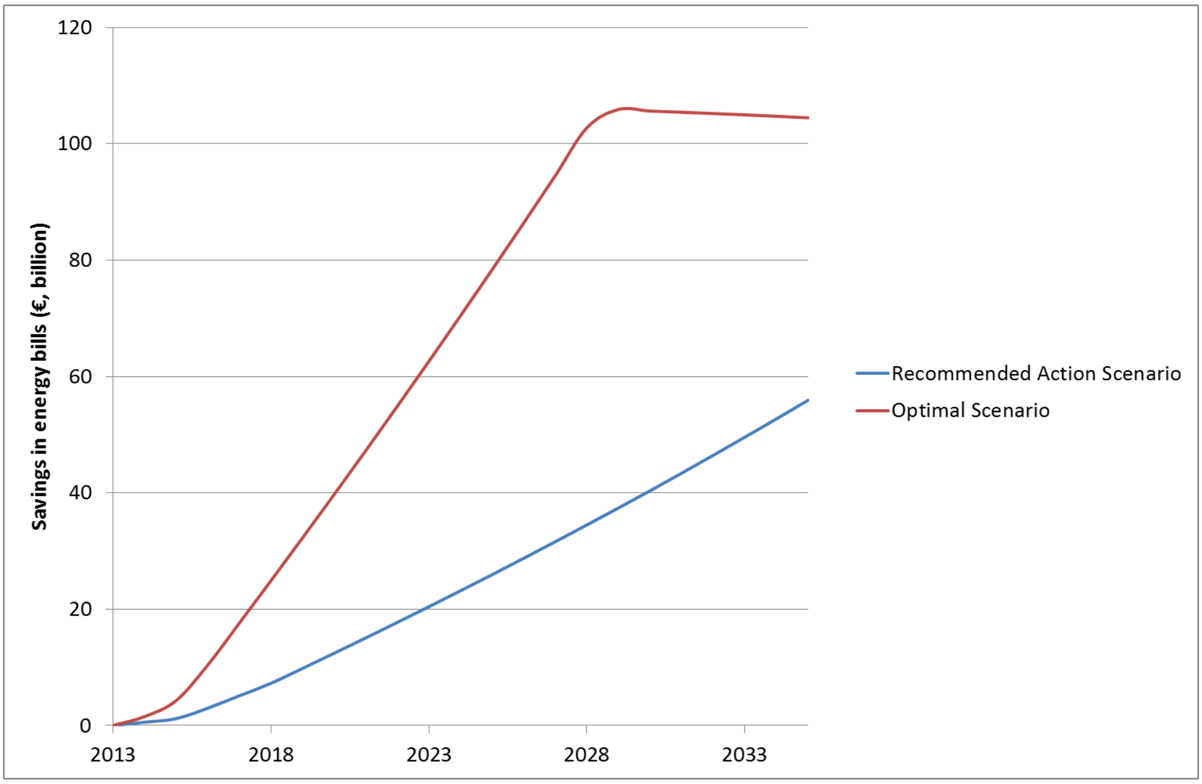


Recommended Action Scenario they rise up to near €5 billion by 2019 and remain near that level to the end of the scenario period. In both cases, incremental investments eventually drop away to zero compared to the Reference Scenario as maximum penetration is reached and the market becomes a replacement market, although this occurs beyond the end of the scenario period for the Recommended Action Scenario.

The value of avoided energy bills attributable to this investment is shown in Figure 23. Under the Optimal Scenario, savings in annual energy bills rise to just under €106 billion in 2029, and then remain at a similar level to the end of the scenario period as the savings from BAT/BEMS under the Reference Scenario begin to catch up. In the Recommended Action Scenario, annual energy bill savings peak at just under €56 billion at the end of the scenario period. Cumulative total additional energy bill savings from 2013 to 2035 are €1 464 billion under the Optimal Scenario and €562 billion under the Recommended Action Scenario. These are 9.2 and 5.9 times, respectively, as great as the magnitude of the additional investment over the period.

The average payback periods are much shorter than the service life of the technology. Despite variation across building types and economies owing to variations in energy prices and energy consumption, investment in BAT/HEMS is generally cost-effective providing the design, installation, commissioning and operation of the systems is appropriate for the building type considered.

**Figure 23. Savings in European residential building energy bills under the Recommended Action and Optimal Scenarios from 2013 to 2035.**



# 6. Accelerating savings from controls: issues to be addressed

As the previous section showed adoption of BAT/BEMS/HEMs is well below the economically optimal level, which indicates that there is currently insufficient investment in these energy savings and productivity raising technologies. One reason for this is that most BAT/BEMS that are installed are not working that well and are poorly managed, such that overall it is thought that about 90% of commercial and public building floor space is inadequately or poorly controlled.

Many control problems are found in practice. The worst cases are where the heating and cooling systems 'fight' each other, i.e. one part of the space is being heated while another part is being cooled. This can often happen even when BAT/BMS/BEMS are installed because they are not being properly used or there are other systemic failures. Setting deadbands for heating and cooling too close together is a common contributing factor.

The building services controls industry in Europe has developed relatively slowly compared with other industries that use microprocessor-based technologies and communications. This is because of a number of reasons, of which the principal ones are:

- lack of general awareness, understanding and appreciation of the importance of HVAC and energy control systems
- slow response from HVAC equipment manufacturers to incorporate advances into their packaged controls and communications
- a lack of common standards enabling BMS/BEMS suppliers to develop more universal products
- a poor standard of client briefing and technical specification, resulting in lowest-cost solutions regardless of the effect and leading to selection on the basis of lowest capital cost rather than highest value in operation
- the economic situation depressing demand, although perversely the economic situation would result in greater uptake of BAT/BEMS if clients were aware of the cost-benefits that can be achieved from appropriately specified and operated BMS.

BAT often fails to deliver its full potential because those specifying the system have limited understanding of how it will be operated and have little experience of operating the systems they have specified. In general, there is a need to move to a market where consultants, contractors and suppliers are selected on the basis of their ability to demonstrate that they understand how the BAT will be used in operation, rather than just on their design experience.

Problems may arise because of:

- an inadequate potential for the building energy system to be properly controlled, i.e. the system is not controllable
- the different control systems applied to specific components or elements not being interoperable and having conflicting control regimes
- the wide range of user interfaces available, and situations where users have no access to the control systems, often resulting in systems being overridden manually.

These problems are compounded by a lack in training for building O&M teams with respect to the operation of BSE systems and the BAT that is intended to control and monitor them.

Addressing these issues is not principally a hardware issue, but much more focus is required with respect to the following human interface/operation considerations (see section 3):

i) briefing and the building life cycle
ii) best practice procurement
iii) making use of occupant-/user-feedback design and implementation
iv) lifetime product management

v) O&M
vi) performance-based service provision
vii) real-time energy monitoring and continuous commissioning.

Overall, the success of a building and its BAT is best judged by the occupier and the occupants, but energy performance needs to be monitored, diagnosed and acted upon. Putting in place systems to address or improve all of the above is essential, especially to encourage greater use of continuous commissioning, which has been shown to be highly effective at identifying important building control problems that would otherwise remain unnoticed.

Table 4 summarises the generic barriers to energy efficiency that also apply to building energy saving controls. Table 5 summarises some of the specific barriers to effective control of building energy systems and some of the opportunities for improvement.

**Table 4. Barriers to and opportunities for effective building automation technology/building energy management-induced energy savings (adapted from *World Energy Outlook 2012* © OECD/IEA, 2012; IEA 2012b: Chapter 9, p. 280).**

| | Barrier | Effect | Remedial policy tools |
|---|---|---|---|
| VISIBILITY | EE is not measured | EE is invisible and ignored | Test procedures/measurement protocols/efficiency metrics |
| | EE is not visible to end users & service procurers | EE is invisible and ignored | Ratings/labels/disclosure/benchmarking/audits/real-time measurement and reporting |
| PRIORITY | Low awareness of the value proposition among service procurers | EE is undervalued | Awareness-raising and communication efforts |
| | Energy expenditure is a low priority | EE is bundled-in with more important capital decision factors | Regulation, mechanisms to decouple EE actions from other concerns |
| ECONOMY | Split incentives | EE is undervalued | Regulation, mechanisms to create EE financing incentives for those not paying all or any of the energy bill |
| | Scarce investment capital or competing capital needs | Underinvestment in EE | Stimulation of capital supply for EE investments, incubation and support of new EE business and financing models, incentives |
| | Energy consumption and supply subsidies | Unfavourable market conditions for EE | Removal of subsidies |
| | Unfavourable perception and treatment of risk | EE project financing cost is inflated, energy price risk under-estimated | Mechanisms to underwrite EE project risk, raise awareness of energy volatility risk, inform/train financial profession |
| CAPACITY | Limited know-how on implementing energy-saving measures | EE implementation is constrained | Capacity-building programmes |
| | Limited government resources to support implementation | Barriers addressed more slowly | Shift government resources toward efficiency goals |
| FRAGMENTATION | EE is more difficult to implement collectively | Energy consumption is split among many diverse end uses and users | Targeted regulations and other EE enhancement policies and measures |
| | Separation of energy supply and demand business models | Energy supply favoured over energy service | Favourable regulatory frameworks that reward energy service provision over supply |
| | Fragmented and under-developed supply chains | Availability of EE is limited and it is more difficult to implement | Market transformation programmes |

*Abbreviation:* EE = energy efficiency.

**Table 5. Barriers to and opportunities for effective building automation technology/building energy management-induced energy savings**

| Barriers and opportunities for effective control | Applicable to domestic building sector | Applicable to non-domestic building sector | Effect on energy efficiency/carbon emissions | Means to overcome barrier/maximise opportunity |
|---|---|---|---|---|
| Poor operation | Yes | Yes | Yes | Multiple and include continuous commissioning, changes in procurement practice, education, guidance, legislation and incentives. |
| Inadequate training or status of building service engineers | Yes | Yes | Yes | Campaign for protected status for the title Engineer in all countries where it is not protected.<br>Designs should only be signed off by suitably experienced and qualified engineers. |
| Inadequate control specifications | Some, but majority put in to meet minimum building regulations in many countries, thus these are the driver of demand and need to be specified correctly. | Vast majority of control specifications are totally inadequate; building regulation guidance is often poorly written. | Yes | Education – most specifiers have inadequate understanding of good control principles.<br>Promote better specification via professional bodies, etc., and encourage governments to improve building regulations and associated guidance documents.<br>Develop control specification generation tools and help facilities. |
| Uncontrollable systems – services that cannot be effectively controlled due to poor hydraulics, incorrect plant selection, etc. | Yes, but only on more complex systems | Yes, as residential but more so | Yes | Education, guidance, controllability reviews by competent persons; would require significant training. Commissioning management reporting direct to the client during design and construction. |
| Poor information on how products work from agents/specialist installers | Yes | Yes | Yes | Documentation will help, but education and training essential, plus need to have knowledge of broader picture. Unbiased advice. |
| Procurement of lowest-cost controls | Yes | Yes | Yes | Improve education and specification standards. |
| Improved communication with plant items such as BACnet etc. | Yes | Yes | Yes | Encourage equipment/plant manufacturers to adopt industry standard interfaces with BMS for all plant. |
| Inadequate plant space | Yes | Yes | Yes | Educate architects, project managers, building owners, etc. |
| Complex services | Yes | Yes | Yes | Education, guidance, controllability reviews, standard proven system designs. |
| Poor documentation on how products work, e.g. CHP, biomass | Yes | Yes | Yes | Improved manufacturer documentation, standards for documentation on product types, standards for integration into systems. Manufacturers can be very blinkered and must understand the bigger picture. Unbiased advice. |

*(continues on next page)*

**Table 5 *(continued)***

| Barriers and opportunities for effective control | Applicable to domestic building sector | Applicable to non-domestic building sector | Effect on energy efficiency/carbon emissions | Means to overcome barrier/maximise opportunity |
|---|---|---|---|---|
| Renewables, biomass, CHP, solar, etc. Guidance on control and correct integration of renewables is poor | Yes | Yes | Yes | Documentation will help, but education and training essential, plus need to have knowledge of broader picture. Unbiased advice. |
| Poorly designed control interfaces | Yes | Yes | Yes | Improve user friendliness – standards training product certification. |
| Interfaces unavailable or inaccessible to building users resulting in system override | Yes | Yes | Yes | Better education, specification, legislation, acceptance standards, etc. |
| Systems that are too complex for users to manage | Yes | Yes | Yes | Simplify where possible, but if essential to have complex systems initiate means to manage effectively, e.g. bureau services. |
| Common programming languages | No | Yes | Yes | Develop standard programming methods/standards to enable standard ways to program devices regardless of manufacturer. This would probably need to be an EU standard for it to be effective, but would have significant long-term benefits. |
| Reduced number of major suppliers: many European controls companies have been taken over or merged with larger organisations, thus reducing competition and potentially reducing innovation. At the other end, small companies struggle to get into the marketplace | Yes | Yes | Yes | Better specifications and common programming methods etc. will lead to a more level marketplace. Specifiers and end clients require better education on how to select products and tenderers for larger projects. |

*Abbreviations:* BMS = building management systems; CHP = combined heat and power.

# 7. Recommended actions

Very little policy attention has been paid to control systems, which is surprising given that building automated controls, operated with or without BEMS, have tremendous potential to save energy cost-effectively in Europe's building stocks. All too often, however, the potential is squandered owing to poor design and implementation of the building automated control systems. In addition, uptake of automated energy-saving controls is far below the levels that are economically justified, and fundamentally measures are needed that will:

- increase the reliability of the savings from BAT/BEMS and HEMS
- increase the uptake of BAT/BEMS and BAT/HEMS.

The recommendations in this section aim to address these needs and to stimulate a debate among energy-efficiency practitioners and policymakers about how best to meet these needs. They are not comprehensive but cover many of the most pressing needs; however, it is recommended that more detailed work be done to refine the analyses considered here (and the related recommendations) prior to any move toward implementation.

## 7.1 Promotion of continuous commissioning

The clear message from experts in the field, case studies and EU-funded projects such as Harmonac (www.harmonac.info) and iSERVcmb (www.iSERVcmb.info) is the vital importance of moving towards continuous commissioning. No matter how well building services equipment and their control systems are thought to be designed, installed and commissioned, real-world experience suggests that many very costly failures (from the point of view of high energy or water bills) are likely to occur and go undiagnosed without a proper expert monitoring feedback and diagnostics process empowered with the authority to intervene to remedy significant failures when identified. It is difficult to mandate the use of continuous commissioning and nor should this even be considered until there is sufficient competence in the quality of continuous commissioning services offered in the supply chain, but much can be done both to stimulate demand for continuous commissioning and to strengthen and maintain the quality of continuous commissioning service provision. Quality and extra capacity can be developed through processes to establish training, service provision guidelines, best practice procurement guidance and accreditation and certification of continuous commissioning service provision. Demand can be built by promoting the benefits of continuous commissioning and through the provision of targeted incentives. The incentives can be financed through many sources, but linking the finance (if not the service provision) to utility finance streams that can be recovered through rates have the advantage of avoiding drains on cash-short exchequers while ensuring overall energy costs are constrained or reduced.

**Recommendation:** Promote high-quality continuous commissioning targeted at ensuring that building energy control is effective, with suitable capacity building, quality-assurance, promotional and incentive measures to overcome market barriers and stimulate demand. Note that if structured properly, early-stage capacity building and financial support can be reduced in time as continuous commissioning becomes more widespread in the marketplace and its benefits become more widely communicated and disseminated, thereby allowing a natural volume market for continuous commissioning services to develop. Continuous commissioning is especially needed in larger buildings.

## 7.2 Advanced analysis techniques

Methods to automatically highlight deficiencies in building services and associated controls performance are needed as it would be unviable for experts to analyse system performance for all buildings on an ongoing basis from a practical and financial viewpoint.

Much excessive energy consumption can be identified with relatively simple rules, and there is considerable potential for expert and other rule-based automated diagnostic systems to identify wastage. Demonstration systems were developed by the Building Research Establishment in the UK many years ago, but programming costs at the time were too high for widespread uptake. Manufacturers and others have since undertaken some development in this area, but little has been commercialised.

In addition to expert systems, techniques such as data mining have considerable potential. These can identify patterns in the vast numbers of data available from BMS and can identify when systems are not working as expected. They can assist in the ongoing analysis of systems to improve energy performance and, as with expert systems, identify when systems are performing poorly and the likely causes.

There has been a significant increase in meter provision and sub-metering, yet very little is done with the results. Where sub-metering is available and analysed, it is often in isolation from BMS which actually control much of the energy usage; recommended actions are often made by 'energy experts' who have very little understanding of the actual complexities of effective modern building control systems, which often leads to counterproductive advice. Advanced analysis techniques linking systems operation and metering are essential to facilitate more objective and effective analysis of system operation and energy efficiency. This can lead to more effective fine-tuning of systems with effective feedback of the results.

These techniques are being developed in the USA, but little appears to have been done in Europe. While much of the technology is similar, there are many differences between the European and US marketplaces. These include both the types of systems installed and the way they are used and operated. Development of systems suitable for the European marketplace has enormous potential for improving energy efficiency.

**Recommendation:** Promote development of advanced data-analysis techniques and routes to market. These tools will be of significant benefit and complementary to continuous commissioning and associated factors in improving building performance.

## 7.3 Capacity building

As has been alluded to in earlier sections of this report, significant capacity constraints affect the proficient delivery of the energy savings potential of building automated controls. These involve at least the following:

- inadequate specification and installation of building energy controls and automation systems
- improper commissioning of BAT/BEMS and BAT/HEMS
- insufficient knowledge of BAT/BEMS and BAT/HEMS, options and practices among building code and energy performance certification requirement designers.

Consequently, it is recommended that structured efforts be made to develop a supply of high-quality service providers through the establishment of dedicated training, certification and accreditation efforts.

The training and other resource development needs encompass building services engineers as well as systems integrators. Control systems should be designed by the building services engineers, or controls specialists working for the designers, as this is included within their professional responsibilities. Development of control strategies cannot be left to systems integrators who have neither designed the services nor selected the associated plant. Systems integrators should develop the specifications into detailed working drawings of system/control strategies etc. to facilitate their implementation.

**Recommendation:** Build capacity among building energy controls service providers and professional/consulting engineers through the establishment of dedicated training, certification and accreditation and the provision of practical and usable expert guides and tools to facilitate appropriate design, installation and commissioning of automated building energy controls.

## 7.4 Strengthening interoperability and standardisation

Despite the growing use of BACnet, there are still many problems with constrained interoperability of building energy services equipment and their control systems. Industry and government need to work closely to address these issues and ensure that appropriate communication protocols are adopted universally so that all systems can function together. This may need encouragement for some service providers to forgo insisting on their proprietary communication systems to enable alternative open protocols to be used. Professional bodies and government can support this through encouragement, awareness-building among those involved in the specification and procurement process, the development of product quality compliance certification that is limited to products that use open protocols and the supply of incentives for which only interoperable products are eligible.

Standardisation of control strategy programming techniques and documentation of system operation is also required to facilitate more rapid transfer of skills within the controls industry and assist understanding of system operation by building services engineers and others who are responsible for system acceptance and ongoing operation.

**Recommendation:** Strengthen market rewards for interoperable products by way of awareness-building measures targeting the supply chain, product compliance/quality certification and incentives.

## 7.5 Educating the market and supply chain

Limited awareness of the potential for savings through BAT/BEMS combined with continuous commissioning is one of the main barriers to greater uptake of effective control solutions. Payback periods are generally very favourable and are shorter than the rather arbitrary 2 years that many procurement processes claim to apply; however, knowledge of the options, potentials and pitfalls is lacking and this creates a latent barrier to adoption as procurement managers are reluctant to invest in goods and services with uncertain benefits. Given the complexity of many BAT/BEMS and the array of competing options, claims and counterclaims, this is a difficult marketplace within which to establish clarity, and much needs to be done to build both confidence and awareness among procurers and operation manager. Actors in the BAT/BEMS supply chain need to be more proactive in clarifying the value proposition in unambiguous and comparable terms so that success and failure can be more clearly established and the light shone on poor service provision as clearly as on good service provision. Developing common and agreed product and service delivery standards and protocols would be very beneficial in this respect; this is an area where professional bodies and market actors can aim to take a lead. The advent of the eu.bac certification scheme (www.eubaccert.eu), wherein controls may be certified for eu.bac compliance, is a welcome example of this, but more is needed to encourage engagement and extension to other areas in the supply chain, including developing service quality norms and certification/accreditation for those engaged in specifying, installing and commissioning systems. The eu.bac System scheme addresses much of this need but requires broader support to ensure it is implemented at scale across the whole industry.

Equally, work is needed to educate the demand side by raising awareness of the value proposition, technical options and qualified service provision among system designers/specifiers, procurement managers and operations managers. Most critically there is a need to educate the market about the value of following up installation and commissioning with expert operations support through continuous commissioning. Both government and industry have a part to play in this process. Similar issues occur for the BAT/HEMS market and supply chain where end-user awareness of the savings potential and paybacks is very limited and value proposition is muddled owing to a lack of transparency and comparability in service delivery.

**Recommendation:** Government and industry (both on the supply and demand sides) to work cooperatively to develop and implement a supply- and demand-side awareness-raising, education and quality-assurance programme, building upon the existing eu.bac System scheme.

## 7.6 Stimulating demand

Demand stimulation is critical and needs to address not just the building automated controls and management systems directly but also the other key areas in the supply and delivery chain: qualified design and specification; educated procurement; qualified contractors and installation engineers; qualified and competent commissioning engineers; competent facilities/building services operation supported by continuous commissioning. Demand for all these goods and services can be stimulated by a judicious blend of awareness-raising, quality assurance, standardisation, innovative financing mechanisms and incentives and appropriate regulation. These issues are addressed individually in other sub-sections within this section of this report; however, it is essential to ensure that demand stimulation is not promoted in a self-serving manner designed simply to ship more BAT/BEMS/HEMS in the near term but rather is done in a holistic manner that maximises the chances of real energy savings being delivered and high end-user satisfaction. In the long term this is essential if the industry is to prosper, as poor user experience and unfulfilled savings potential serve to poison the market and prevent repeat business. It is in the collective interests of all those engaged in the BAT/BEMS and BAT/HEMS supply chain to improve both delivery and transparency of the services delivered so that the value proposition can be more clearly articulated and experienced. Part of this would be expected to occur automatically if there is greater use of existing good energy management practice, as set out in the standard EN IS0 50001, thus promotion of energy management in general can also be driver of demand for improved building energy control.

**Recommendation:** Government and industry to cooperatively develop a programme to drive demand at scale for reliable high-quality BAT/BEMS/HEMS goods and services to be stimulated by a judicious blend of awareness-raising, quality assurance, standardisation, innovative financing mechanisms and incentives and to be supported by promotion of more broadly based good energy management practice such as EN ISO 50001.

## 7.7 Finance and incentives

Investment in BAT/BEMS and BAT/HEMS is lower than it would appear to be in the economic interests of service procurers, which is evidence of some kind of market failure. Lack of awareness combined with wariness as a result of an uncertain value proposition are key components of this, and these are compounded by all the usual, better-known market failures that constrain investment in building energy efficiency measures. This reluctance to invest can be overcome in part through the provision of targeted incentives and financing instruments that preferentially reward good practice in the supply chain while reducing risk in the specification and procurement process. Significant incentives are likely to be needed at the outset if scale demand is to be established, but these should be closely tied to quality service provision and should grow (ramp-up) no faster than the supply chain is capable of meeting the service needs. Financing is thus also needed to support strengthening quality in the supply chain (through measures such as training, education, certification and accreditation) at as least as fast a pace as it is needed to directly stimulate demand to ensure that the extra demand is not met by sub-standard service and hence avoid future market poisoning risk. In principle, incentives can be financed from many sources, but utility revenue linked to rate recovery through pay-as-you-save types of mechanisms is obviously an attractive option in times when central government revenues are under pressure.

Over the longer term, the migration to fully self-financing mechanisms must be the goal. This can be stimulated through promotion of a variety of mechanisms. Energy service company (ESCO) financing and energy performance contracting can be part of the solution, but capacities will need to be built and performance demonstrated for such mechanisms to be established as standard business models in a risk-averse marketplace. Industry (both supply and demand sides) and government can do much to advance this through coordinated actions.

**Recommendation:** Develop well-timed and targeted financial incentive mechanisms designed to stimulate supply and demand of quality BAT/BEMS/HEMS products and services at as fast a scale (rate of growth) as can reasonably be sustained without risk of market poisoning through unqualified service delivery. Simultaneously facilitate and promote innovative contracting and financing mechanisms that reduce upfront cost risk and ties rewards to the successful delivery of downstream energy savings. Note that given the vast scale of the cost-effective energy and bill savings that are potentially achievable with BAT/BEMS/HEMS, it is appropriate for these mechanisms to be designed to be of sufficient scale to help access a large part of this potential. Given the large sums likely to be involved, it is appropriate that significant preparatory work should be done to design these schemes to be cost effective at scale.

## 7.8 Existing policy levers

The two principal pieces of European legislation that can support the delivery of greater and more effective BAT/BEMS/HEMS are the Energy Performance of Buildings Directive (EPBD) (EC 2002, 2010, 2012a, 2012b) and the Energy Efficiency Directive (EED) (EC 2012c). The Energy Services Directive (ESD) also has some relevant provisions (EC 2006). The discussion below summarises the key text from each Directive and considers the practical implications of these measures to support the improved and accelerated deployment of BAT/BEMS/HEMS. In many cases EU Member States have considerable latitude regarding how they react to and respond to these provisions, and it is in the practical implementation of these EU-originated policy instruments at Member State level that the potential to advance savings through BAT/BEMS/HEMS will be seen. The European Commission has announced its intention to review the EPBD in 2016 and the EED in 2014. The intended focus of these reviews is on practical implementation issues, which in both cases present an opportunity to constructively strengthen the measures that will support energy savings through BAT/BEMS/HEMS.

### *Energy Performance of Buildings Directive (EPBD)*

Regulations that require realistic improvements in energy efficiency will always have a beneficial effect for the controls industry, as controls are one of the most cost-effective means to improve energy performance. One of the major forces to stimulate demand for improved controls is legislation, and the EPBD of 2002 (EC 2002) as recast in 2010 (EC 2010b) includes specifications that should stimulate increased demand within it, as follows.

> *Article 8*
>
> *Technical building systems*
>
> *1. Member States shall, for the purpose of optimising the energy use of technical building systems, set system requirements in respect of the overall energy performance, the proper installation, and the appropriate dimensioning, adjustment and control of the technical building systems which are installed in existing buildings. Member States may also apply these system requirements to new buildings.*
>
> *2. Member States shall encourage the introduction of intelligent metering systems whenever a building is constructed or undergoes major renovation, whilst ensuring that this encouragement is*

*in line with point 2 of Annex I to Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity (1). Member States may furthermore encourage, where appropriate, the installation of active control systems such as automation, control and monitoring systems that aim to save energy.*

The first paragraph requires systems requirements to be specified in building codes that address control systems installed in existing buildings, while the second mandates the adoption of intelligent energy metering systems. As EU Member States are amending their building codes to comply with these provisions, there is an opportunity to mandate appropriate control systems in building renovations, which will help to drive the market; however, the devil will be in the detail and it is important that real expertise is brought to bear on the framing of these specifications to ensure they are not counterproductive.

By way of illustration of the kinds of problems that can occur, the UK Building Regulations Part L incorporates compliance guides for both domestic and non-domestic buildings that include a number of controls requirements. However, while some are appropriate, the majority are poorly written or overly simplistic and do not reflect current good practice. The clauses are often used in the specifications and interpreted by systems integrators; however, most systems integrators and even some specialist controls consultants are unfamiliar with these compliance guides and when given copies often decide to ignore them as they are considered to be so poor. The sorts of problems that can occur are exemplified by the specifications for Zone Control. Controlling different zones of a building according to occupancy, required temperature, etc., is good practice and has been incorporated into the UK building regulations compliance guidance, BREEAM, etc.; however, modern control of individual emitters for occupancy, temperature, etc., complete with demand-based control of main plant is far more effective.

It is not unknown for zone valves to comply with building regulations and BREEAM to be insisted upon, despite the installation of modern controls including those for individual emitters for occupancy, temperature, etc. and demand-based control of main plant. In some cases the use of three-port zone valves has compromised the operation of variable-flow systems that have been incorporated using advanced controls.

**Recommendation:** While provisions requiring the use of adequate controls in new buildings and renovations are necessary to stimulate uptake of energy-saving controls, there needs to be much greater reflection regarding how they should be framed and specified to ensure that they are clear, usable and encourage good practice. It is recommended that an expert task force be established to prepare guidelines on these specifications and to review/critique existing specifications. To ensure that the recommendations reflect real application, the task force should include review from practitioners who would be expected to use the requirements and not just from experts in the control industry or researchers. Once clarity on the optimal regulatory specifications has been established, EU Member States should move to implement them fully in their building codes and to monitor implementation experience to ensure desired results are being achieved, making informed adjustments if not. The European Commission could facilitate coordination of this process.

The recast EPBD also includes the following provisions on inspection of heating and air-conditioning systems:

*Article14*

*Inspection of heating systems*

*1. Member States shall lay down the necessary measures to establish a regular inspection of the accessible parts of systems used for heating buildings, such as the heat generator, control system and circulation pump(s), with boilers of an effective rated output for space heating purposes of* *more than 20 kW. That inspection shall include an assessment of the boiler efficiency and the boiler sizing compared with the heating requirements of the building. The assessment of the boiler sizing does not have to be repeated as long as no changes were made to the heating system or as regards the heating requirements of the building in the meantime.*

*Member States may reduce the frequency of such inspections or lighten them as appropriate, where an electronic monitoring and control system is in place.*

*Article 15*

*Inspection of air-conditioning systems*

*1. Member States shall lay down the necessary measures to establish a regular inspection of the accessible parts of air-conditioning systems of an effective rated output of more than 12 kW. The inspection shall include an assessment of the air-conditioning efficiency and the sizing compared to the cooling requirements of the building. The assessment of the sizing does not have to be repeated as long as no changes were made to this air-conditioning system or as regards the cooling requirements of the building in the meantime. Member States may reduce the frequency of such inspections or lighten them, as appropriate, where an electronic monitoring and control system is in place.*

These provisions create a direct incentive to use BAT/BEMS/HEMS to monitor and control the systems as they lighten the inspection costs on such systems; however, they make an assumption that any electronic monitoring and control system will be adequate rather than specifying quality-assurance requirements.

**Recommendation:** The national implementation of these measures and the future revision of the EPBD should consider introducing quality-assurance requirements to electronic monitoring and controls systems that are exempt from inspections.

### *Energy Efficiency Directive (EED)*

Directive 2012/27/EU (EC 2012c) contains the italicised text below that is relevant to the uptake of BAT/BEMS/HEMS.

The EED imposes an obligation on central government buildings to undergo deep renovations; however, it allows Member States to take alternative cost-efficient measures to achieve an equivalent improvement in the energy performance of the buildings within their central government estate. This is an opportunity to promote proper adoption of BAT/BEMS within central government estates and pioneer improvement/rationalisation within the sector.

*15) The total volume of public spending is equivalent to 19% of the Union's gross domestic product. For this reason the public sector constitutes an important driver to stimulate market transformation towards more efficient products, buildings and services, as well as to trigger behavioural changes in energy consumption by citizens and enterprises. Furthermore, decreasing energy consumption through energy efficiency improvement measures can free up public resources for other purposes. Public bodies at national, regional and local level should fulfil an exemplary role as regards energy efficiency.*

*16) Member States should establish a long-term strategy beyond 2020 for mobilising investment in the renovation of residential and commercial buildings with a view to improving the energy performance of the building stock. That strategy should address cost-effective deep renovations which lead to a refurbishment that reduces both the delivered and the final energy consumption of a building by a significant percentage compared with the pre-renovation levels leading to a very high energy performance. Such deep renovations could also be carried out in stages.*

*17) The rate of building renovation needs to be increased, as the existing building stock represents the single biggest potential sector for energy savings. Moreover, buildings are crucial to achieving the Union objective of reducing greenhouse gas emissions by 80−95% by 2050 compared to 1990. Buildings owned by public bodies account for a considerable share of the building stock and have high visibility in public life. It is therefore appropriate to set an annual rate of renovation of buildings owned and occupied by central government on the territory of a Member State to upgrade their energy performance.*

*It should be possible for Member States to take alternative cost-efficient measures to achieve an equivalent improvement of the energy performance of the buildings within their central government estate. The obligation to renovate floor area of central government buildings should apply to the administrative departments whose competence extends over the whole territory of a Member State.*

Given these provisions there is an opportunity to ensure that effective BAT/BEMS service delivery is factored into the renovation delivery plan led by the public sector.

The Directive also requires Municipalities to adopt integrated and sustainable energy-efficiency plans (Paragraph 18 below). Complementary measures are needed, however, to ensure that those drawing up these plans are aware of the BAT/BMS opportunities and issues and have factored measures to address these into their thinking.

*18) …Member States should encourage municipalities and other public bodies to adopt integrated and sustainable energy efficiency plans with clear objectives, to involve citizens in their development and implementation and to adequately inform them about their content and progress in achieving objectives. Such plans can yield considerable energy savings, especially if they are implemented by energy management systems that allow the public bodies concerned to better manage their energy consumption. Exchange of experience between cities, towns and other public bodies should be encouraged with respect to the more innovative experiences.*

**Recommendation:** EU Member States should take the opportunity when deriving plans to implement the requirements of paragraphs 16, 17 and 18 of the EED to ensure that all public sector renovation stimulated through these provisions requires the use of quality-assured BAT/BEMS products and services. These should consider including strong requirements/incentives for the preferential procurement of continuous commissioning services to ensure best practice BAT/BMS service delivery.

### *Public procurement*

The EED also contains the following provision addressing energy-efficient public procurement which if appropriately implemented at Member State level could provide another lever to stimulate demand and build capacity in best practice BAT/BEMS service delivery.

*19) With regard to the purchase of certain products and services and the purchase and rent of buildings, central governments which conclude public works, supply or service contracts should lead by example and make energy-efficient purchasing decisions. This should apply to the administrative departments whose competence extends over the whole territory of a Member State.*

*When in a given Member State and for a given competence no such relevant administrative department exists that covers the whole territory, the obligation should apply to those administrative departments whose competences cover collectively the whole territory.*

*The provisions of the Union's public procurement directives should not however be affected. For products other than those covered by the energy efficiency requirements for purchasing in this Directive, Member States should encourage public bodies to take into account the energy efficiency of purchase.*

**Recommendation:** EU Member States should take the opportunity when deriving plans to implement the requirements of paragraph 19 of the EED to ensure the setting of appropriate public procurement specifications that drive demand for quality-assured BAT/BEMS products and services within the public sector buildings stock. These should consider including strong requirements/ incentives for the preferential procurement of continuous commissioning services to ensure best practice BAT/BMS service delivery.

### *Energy-efficiency obligations*

Paragraph 20 of the EED calls for national energy-efficiency obligation schemes, applicable to energy suppliers, to be established under a common EU framework. If adopted by Member States this presents an opportunity for utilities to offer best practice BAT/BEMS/HEMS services and subsidise or amortise their implementation, thereby introducing patient supply-side capital into building services energy-savings delivery and providing an incentive to ensure savings are real rather than perceived. However, it is important to recognise that energy-market regulators have a large role to play in ensuring that there is a true incentive for utilities to deliver real rather than nominal savings through such mechanisms. Proper monitoring, verification and evaluation of savings delivered will be essential if this is to function as intended, and it may also be appropriate to consider separating the funding stream from the service delivery.

> *20) An assessment of the possibility of establishing a 'white certificate' scheme at Union level has shown that, in the current situation, such a system would create excessive administrative costs and that there is a risk that energy savings would be concentrated in a number of Member States and not introduced across the Union. The objective of such a Union-level scheme could be better achieved, at least at this stage, by means of national energy efficiency obligation schemes for energy utilities or other alternative policy measures that achieve the same amount of energy savings. It is appropriate for the level of ambition of such schemes to be established in a common framework at Union level while providing significant flexibility to Member States to take fully into account the national organisation of market actors, the specific context of the energy sector and final customers' habits. The common framework should give energy utilities the option of offering energy services to all final customers, not only to those to whom they sell energy. This increases competition in the energy market because energy utilities can differentiate their product by providing complementary energy services. The common framework should allow Member States to include requirements in their national scheme that pursue a social aim, in particular in order to ensure that vulnerable customers have access to the benefits of higher energy efficiency. Member States should determine, on the basis of objective and non-discriminatory criteria, which energy distributors or retail energy sales companies should be obliged to achieve the end-use energy savings target laid down in this Directive.*

**Recommendation:** EU Member States should consider elaborating the Paragraph 20 requirements into the development of obligations for utilities to include the offer of financing for best practice BAT/BMS/HEMS service delivery, financial incentives, capacity building and related programmatic support within national energy-efficiency obligation programmes. Energy-market regulators should ensure appropriate quality-assurance and incentive structures are in place to ensure real energy savings are being delivered through such mechanisms.

### *Promotion of continuous commissioning through mandated energy audits*

Paragraph 24 of the EED requires that Member States develop programmes to stimulate energy audits among small and medium-sized enterprises (SMEs). Noting that 'energy audit' is defined in the Directive as '*a systematic procedure with the purpose of obtaining adequate knowledge of the existing energy consumption profile of a building or group of buildings, an industrial or commercial operation or installation or a private or public service, identifying and quantifying cost-effective energy savings* *opportunities, and reporting the findings*', implementation of this requirement could be elaborated into the provision of systematic support for continuous commissioning.

> *24) To tap the energy savings potential in certain market segments where energy audits are generally not offered commercially (such as small and medium-sized enterprises (SMEs)), Member States should develop programmes to encourage SMEs to undergo energy audits. Energy audits should be mandatory and regular for large enterprises, as energy savings can be significant. Energy audits should take into account relevant European or International Standards, such as EN ISO 50001 (Energy Management Systems), or EN 16247-1 (Energy Audits), or, if including an energy audit, EN ISO 14000 (Environmental Management Systems) and thus be also in line with the provisions of Annex VI to this Directive as such provisions do not go beyond the requirements of these relevant standards. A specific European standard on energy audits is currently under development.*

**Recommendation:** EU Member States should consider elaborating the Paragraph 24 requirements into the development of systematic programmatic support for continuous commissioning in the SME building stock and thereby develop continuous commissioning service-delivery capacity and build confidence in BAT/BEMS energy-savings delivery.

### *Exploitation of smart meter provisions*

The EED also includes provisions to stimulate the deployment of smart meters, as follows.

> *27) In relation to electricity, and in accordance with Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity (1), where the roll-out of smart meters is assessed positively, at least 80% of consumers should be equipped with intelligent metering systems by 2020. In relation to gas, and in accordance with Directive 2009/73/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in natural gas (2), where the roll-out of intelligent metering systems is assessed positively, Member States or any competent authority they designate, should prepare a timetable for the implementation of intelligent metering systems.*

> *28) Use of individual meters or heat cost allocators for measuring individual consumption of heating in multi-apartment buildings supplied by district heating or common central heating is beneficial when final customers have a means to control their own individual consumption. Therefore, their use makes sense only in buildings where radiators are equipped with thermostatic radiator valves.*

Note: as written, this could be a disincentive to install TRVs on buildings supplied by district heating networks, and this needs to be considered when the EED is revised. Similarly, there is no stimulus for sub-metering on dynamic plant and equipment for real-time measurement and testing. In principle there should be a focus on metering before intervention as metering has a very low cost-to-value ratio and it is hard to identify potential savings and then measure them following intervention without sub-metering.

> *29) In some multi-apartment buildings supplied by district heating or common central heating, the use of accurate individual heat meters would be technically complicated and costly due to the fact that the hot water used for heating enters and leaves the apartments at several points. It can be assumed that individual metering of heat consumption in multi-apartment buildings is, nevertheless, technically possible when the installation of individual meters would not require changing the existing in-house piping for hot water heating in the building. In such buildings, measurements of individual heat consumption can then be carried out by means of individual heat cost allocators installed on each radiator.*

**Recommendation:** The revision of the ESD and EED should consider elaborating requirements for sub-metering of dynamic plant. Furthermore, the review should consider removal or amendment of any requirements that have unintentionally created disincentives to the installation of TRVs in buildings supplied by district heating networks.

*Renewal of energy meters*

The ESD (EC 2006) requires installation of accurate energy meters that include information on time of use for all new and renovated buildings and all others where they are justified techno-economically. Member States could take advantage of this to (a) better address BAT/BMS/HEMS provisions within building regulations and (b) exploit synergies with BAT/BMS/HEMS opportunities to ensure these are driving appropriate deployment.

> *30) Directive 2006/32/EC* [ESD] *requires Member States to ensure that final customers are provided with competitively priced individual meters that accurately reflect their actual energy consumption and provide information on actual time of use. In most cases, this requirement is subject to the conditions that it should be technically possible, financially reasonable, and proportionate in relation to the potential energy savings. When a connection is made in a new building or a building undergoes major renovations, as defined in Directive 2010/31/EU, such individual meters should, however, always be provided. Directive 2006/32/EC also requires that clear billing based on actual consumption should be provided frequently enough to enable consumers to regulate their own energy use.*

Directive 2009/72/EC (EC 2009a) concerning common rules for the internal market in electricity and Directive 2009/73/EC (EC 2009b) concerning common rules for the internal market in natural gas also have provisions that affect intelligent metering and are referenced in the EED as follows:

> *31) Directives 2009/72/EC and 2009/73/EC require Member States to ensure the implementation of intelligent metering systems to assist the active participation of consumers in the electricity and gas supply markets. As regards electricity, where the roll-out of smart meters is found to be cost-effective, at least 80% of consumers must be equipped with intelligent metering systems by 2020. As regards natural gas, no deadline is given but the preparation of a timetable is required. Those Directives also state that final customers must be properly informed of actual electricity/gas consumption and costs frequently enough to enable them to regulate their own consumption.*

> *32) The impact of the provisions on metering and billing in Directives 2006/32/EC, 2009/72/EC and 2009/73/EC on energy saving has been limited. In many parts of the Union, these provisions have not led to customers receiving up-to-date information about their energy consumption, or billing based on actual consumption at a frequency which studies show is needed to enable customers to regulate their energy use. In the sectors of space heating and hot water in multi-apartment buildings the insufficient clarity of these provisions has also led to numerous complaints from citizens.*

> *33) In order to strengthen the empowerment of final customers as regards access to information from the metering and billing of their individual energy consumption, bearing in mind the opportunities associated with the process of the implementation of intelligent metering systems and the roll out of smart meters in the Member States, it is important that the requirements of Union law in this area be made clearer. This should help reduce the costs of the implementation of intelligent metering systems equipped with functions enhancing energy saving and support the development of markets for energy services and demand management. Implementation of intelligent metering systems enables frequent billing based on actual consumption. However, there is also a need to clarify the requirements for access to information and fair and accurate billing based on actual consumption in cases where smart meters will not be available by 2020, including in relation to metering and billing of individual consumption of heating, cooling and hot water in multi-unit buildings supplied by district heating/cooling or own common heating system installed in such buildings.*

**Recommendation:** It is recommended that the clarification process alluded to in Paragraph 33 of the EED be taken as an opportunity to review the interaction between the smart-metering requirements, sub-metering and BAT/BEMS/HEMS, access to billing information, interoperability issues and the provision of energy services to ensure that the most effective metering requirements are being promoted.

### *BAT/BEMS/HEMS synergies with demand response stimuli*

Paragraphs 44 and 45 of the EED aim to stimulate demand response, as follows:

> *44) Demand response is an important instrument for improving energy efficiency, since it significantly increases the opportunities for consumers or third parties nominated by them to take action on consumption and billing information and thus provides a mechanism to reduce or shift consumption, resulting in energy savings in both final consumption and, through the more optimal use of networks and generation assets, in energy generation, transmission and distribution.*
>
> *45) Demand response can be based on final customers' responses to price signals or on building automation. Conditions for, and access to, demand response should be improved, including for small final consumers. Taking into account the continuing deployment of smart grids, Member States should therefore ensure that national energy regulatory authorities are able to ensure that network tariffs and regulations incentivise improvements in energy efficiency and support dynamic pricing for demand response measures by final customers. Market integration and equal market entry opportunities for demand-side resources (supply and consumer loads) alongside generation should be pursued. In addition, Member States should ensure that national energy regulatory authorities take an integrated approach encompassing potential savings in the energy supply and the end-use sectors.*

**Recommendation:** In principle, the promotion of demand response will also stimulate demand for BAT/BEMS/HEMS; however, it is recommended that the interaction be more thoroughly assessed during the review of the EED to examine the means by which this interface can be strengthened to deliver cost-effective savings.

### *Development of competent energy-efficiency professionals*

Measures to stimulate the development of adequate professional cadres are another important need and the provisions within the EED present an opportunity to support proper design, specification, procurement, installation, commissioning and operation of BAT/BMS/HEMS. Paragraph 46 of the EED specifies:

> *46) A sufficient number of reliable professionals competent in the field of energy efficiency should be available to ensure the effective and timely implementation of this Directive, for instance as regards compliance with the requirements on energy audits and implementation of energy efficiency obligation schemes. Member States should therefore put in place certification schemes for the providers of energy services, energy audits and other energy efficiency improvement measures.*

Given the current lack of qualified professionals working in BAT/BEMS/HEMS delivery within the building services sector, this strengthening of professional capacity is a key need and should be proactively pursued.

**Recommendation:** In the implementation of the provisions within Paragraph 46 of the EED, EU Member States should aim to build capacity among building energy controls service providers and engineers through the establishment of dedicated training, certification and accreditation and the provision of practical and usable expert guides and tools to facilitate appropriate design, installation and commissioning of automated building energy controls. This measure should also target the gap between system specifiers, building services consultants and systems integrators so that systems are correctly designed for controllable operation and robust control strategies specified for the systems integrators to implement.

### *Development of energy service markets and improved procurement practice*

Measures to support the development of energy services markets and improved procurement practices are also needed and are addressed in Paragraphs 47 and 48.

> *47) It is necessary to continue developing the market for energy services to ensure the availability of both the demand for and the supply of energy services. Transparency, for example by means of lists of energy services providers, can contribute to this. Model contracts, exchange of best practice and guidelines, in particular for energy performance contracting, can also help stimulate demand. As in other forms of third-party financing arrangements, in an energy performance contract the beneficiary of the energy service avoids investment costs by using part of the financial value of energy savings to repay the investment fully or partially carried out by a third party.*

> *48) There is a need to identify and remove regulatory and non-regulatory barriers to the use of energy performance contracting and other third-party financing arrangements for energy savings. These barriers include accounting rules and practices that prevent capital investments and annual financial savings resulting from energy efficiency improvement measures from being adequately reflected in the accounts for the whole life of the investment. Obstacles to the renovating of the existing building stock based on a split of incentives between the different actors concerned should also be tackled at national level.*

**Recommendation:** It is recommended that these provisions be implemented with the needs of BAT/BEMS service delivery firmly in mind.

### *Energy labelling*

The EU Energy Labelling Directive (EC 2010a) is currently under review; this presents a timely opportunity to review the scope of the Directive and consider whether it is appropriate and feasible to develop EU mandatory or voluntary energy labelling requirements that could apply to BAT/BEMS/HEMS.

**Recommendation:** Within the context of the review of the EU energy labelling scheme, consider whether it is appropriate to amend the scope to address labelling for BAT/BEMS/HEMS devices and applications.

# Appendix A: Common HVAC control functions

Many control functions are required for the safe and energy-efficient operation of buildings and their services. This appendix outlines some key elements of the energy-efficient operation of heating, ventilation and air conditioning (HVAC) systems, which in many cases offer significant scope for wider and more effective implementation in the European building stock.

### *Optimum start/stop*

Optimum start/stop was introduced over 30 years ago for main heating plant but is now available for individual room controls, from domestic systems to large commercial buildings, and can also be used for cooling and ventilation systems. The need for optimum start/stop is lessened as buildings become better insulated, but energy savings are still possible.

### *Demand-based control (boiler/chiller inhibit)*

Often boiler and chiller plant turns itself on and off to maintain the set-point temperature for hot or chilled water circulation, whether or not there is any demand for heated or chilled water in the building itself, an activity sometimes called 'dry cycling'. Demand-based control inhibits boiler operation unless there is a specific requirement from a zone or emitter. The result can be significantly lower energy consumption during periods of low load. While such losses are far lower with modern equipment than, say, with traditional cast iron boilers with a high water content, there is no point in operating equipment when not required just to top up the circuit temperatures.

Some more advanced domestic heating control systems include this facility, as do many under-floor heating systems. Simpler systems serving radiators on compensated circuits can also be wired to inhibit boiler firing when the compensated circuit valves are on full recirculation.

Modern BEMS that control all elements, from boilers and chillers to terminal units will have enough information to inhibit the operation of main plant unless there is a demand. However, this is often not programmed into the system. Where it is, suitable minimum operating times should be included for stability of operation. If the plant has a long response time, for example when the distribution system is very extensive, demand-based control may not be suitable.

Dedicated dry-cycling controllers are also available that can be attached to boilers to stop them firing when they detect that loads are low. These can make savings – particularly on older and poorly controlled plant – but they are less effective as a means of control, because they do not take proper account of actual system demand. Dedicated controllers may also create problems, for example:

- if suitable BEMS already exist, then a dedicated controller will come between the boiler and the BEMS and actually restrict the potential to improve performance and save energy. A far more effective, lower-energy solution will be to programme demand-based control into the BEMS
- if fitted to modern boilers, a dry cycling controller may inhibit operation at low outputs above minimum turndown, a state in which this equipment is often at its most efficient
- there have also been instances where dedicated dry-cycling controls have caused unsafe boiler operation and users have had to disable or remove them after a short period in use.

### *Multiple-boiler control*

Where there are multiple boilers, traditional sequence control loads the first boiler fully, then brings on the next boiler in line, and so on. It may also change the order of sequencing every week or so, in order to equalise the use of all the boilers. Historically, the two main approaches used have been (i) flow-temperature sequence control and (ii) return-temperature sequence control.

Sequence control from flow temperature will often interact with the boiler control thermostat or modulating control set-point. In practice, this arrangement often performs poorly, owing to instabilities (e.g. all boilers coming on in quick succession and then all going off again) or by failing to take command because the controls packaged with the boilers react more quickly. Sequencing by flow temperature can work effectively where the boilers have modulating burners with which sequence control is correctly integrated. However, to provide suitable operation margins, temperature-limiting control of individual boiler outlet temperatures must also be provided (note: the high-limit safety controls, which must also be provided, must not be used for this purpose).

Historically, sequence control from return temperature has been far more stable and reliable than flow-temperature control. However, it should not be used in modern systems where the flow rate varies, because the return temperature no longer represents the load on the system ($Q = MC\Delta T$), though in practice many service designers and systems integrators do not appreciate this. Many modular boilers now also have individual pumps, to ensure the flow through low water content units and to increase differential temperatures at low loads for condensing boilers.

Modern boilers are normally more efficient at low loads than at higher loads, once they are operating above their minimum turndowns. A number of boiler manufacturers offer packaged control systems that operate the burners in parallel, so all boilers modulate together. However, this effectively acts as one boiler and does not provide stable operation at low loads. A more sophisticated variant modulates the first boiler up to its most efficient level, then does the same for the next, and so on, and these can be set up to work efficiently.

Successful implementation of the most appropriate boiler-control strategies relies on a good understanding of the system hydraulics and careful setting-up of the sequence control so the boiler plant operates safely and efficiently under all load conditions. To sustain this performance also requires effective, ongoing maintenance. Unfortunately, this is rarely found in practice, so the control of multiple boilers is typically poorly managed.

An alternative method is heat-load control, either via a heat meter or via the building management systems (BMS), using flow and return temperature sensors and a suitable flow meter. This provides the following advantages:

- boilers can be enabled and disabled to provide the most efficient operation
- only the lead boiler turns on and off below its minimum modulation range
- simple and easy to set up
- tolerant of most hydraulic arrangements
- different types of boilers can more easily be controlled together
- there is no interference with the packaged boiler controls.

While heat-load control has been available for more than 20 years, in practice it is rarely used because of the additional upfront costs and lack of understanding of its advantages. However, the cost of heat and flow meters is falling, in part owing to greater demand created by government subsidies for renewable technologies.

A few systems integrators embrace the use of heat-load control. The rest do not appreciate its advantages and tend to resist its adoption, often because they do not understand its operation. In practice the greatest problems occur with the heat-meter specification and location:

- for accurate operation, flow meters normally require a minimum of 10 diameters (D) straight pipe upstream and 5 downstream; some ultrasonic meter suppliers recommend 20/10D. This must be very clearly detailed on all drawings, as contractors often do not pay sufficient attention to specifications or instructions, even though EU product certification is compromised if installation is not in accordance with instructions
- the heat meters need an analogue kilowatt output, which is not available on all units. These outputs also need to be compatible with the BMS, but signal converters are readily available if required.

There is thus a significant energy savings potential through the promotion of more effective multiple-boiler control. For modern boilers, the energy savings achievable by operating them within their most efficient ranges are probably in the order of 3−4% compared to sequence-control systems that are well set up. However, since most sequence-control systems are not well set up, in practice good control offers the potential for savings of the order of 10−15%, even if heat-load control is not always included.

### *Multiple-chiller control*

Multiple-chiller control is also often poor. In the days of reciprocating compressors, chillers were unreliable when operated for prolonged periods at low loads, so sequence-control systems were configured to run the first chiller up to full load before starting the second chiller, and so on.

Nowadays, almost all chillers have modulating control from around 20% of full capacity. They are also significantly more efficient at low vs peak loads, owing to the increased condensing and evaporating capacities relative to load. So the energy-efficient approach is to bring on the next unit when the load reaches 40% of one unit's capacity.

Unfortunately, many chiller manufacturers and systems integrators still use control strategies dating from 30 years ago. In many cases this is exacerbated by poor hydraulic arrangements, for example with water flowing equally through off-line and on-line chillers, requiring on-line chillers to operate at lower evaporator temperatures than necessary and thereby reducing their efficiency.

As a result, there is significant potential for energy savings through the promotion of more effective multiple-chiller control. As for multiple boilers, heat-load-based control can be used to optimise the efficient operation of multiple chillers, but again this is rarely implemented owing to the additional cost and a lack of knowledge.

### *Integration of renewable energy systems*

The control problems outlined above are further exacerbated where unconventional and renewable energy systems are used, including biomass boilers, solar panels, heat pumps and combined heat and power (CHP) co-generation systems. Hydraulic arrangements and control strategies for renewables integrated with conventional fossil-fuel boilers are often fundamentally flawed. This creates major potential for energy savings through promoting more effective renewables control and integration.

Equipment manufacturers often have standard arrangements that may suit some applications but not others, and manufacturers and their agents often have poor understanding of wider integration and controls issues. Unfortunately, many system designers blindly follow the advice of manufacturers, even when it is not appropriate to the wider system in which the device is found. Climate and load characteristics are often not properly considered. For examples, solutions that suit continental climates with their marked changes in season do not necessarily work in more humid, more variable, marine climates.

A common fundamental error is to activate back-up fossil-fuel boilers etc. when temperature is not maintained. Depending on the hydraulics, the control and where the temperature is sensed, the fossil-fuel boiler often keeps running and compromises the renewable operation.

Thermal stores and buffer vessels are often poorly controlled, making them ineffective. For example, to recharge the store, the primary flow must exceed the secondary flow, and vice versa to discharge it. In addition, many systems rely purely on thermal-store temperature to control the heat source, so the heat source may not be enabled, even while heat from the store is being drawn down. This can greatly reduce the utilisation of the renewable energy source.

Heat-load-based control systems are usually far more effective in the control of renewables, together with thermal-store temperatures and variable-flow control. Currently these are not widely used, though there is a growing awareness of their value in the technical literature.

### *Direct boiler compensation*

There is significant potential for energy savings through promoting effective direct boiler compensation, reducing boiler flow temperature with increasing ambient temperature. This can reduce the fuel requirement of condensing boilers by up to 8–9% where return temperatures down to 30 °C are possible, by promoting maximum condensing operation. Nowadays direct compensation is rare in domestic buildings in many parts of the EU, but it is more common in Central and Northern Europe, where there is a tradition of running heating systems at lower temperatures for longer hours. However, an increasing number of new condensing boilers include direct compensation.

Direct compensation is particularly easy to apply with combination boilers, which will automatically raise their output to meet any demand for domestic hot water and give this priority over the heating. Domestic system boilers are also available with direct compensation, but interlocks are required to override it when there is a demand from the hot water system cylinder, which needs heating to over 60 °C to avoid the risk of *Legionella*. While the cylinder is being heated, hotter water will also circulate around the space-heating system, unless the hot water is given absolute priority.

Boilers in commercial and public buildings can also be directly compensated. Though not yet common practice (indeed, many boilers only ever work in condensing mode on system start-up), this is beginning to happen across the EU. Care must be taken where large distribution systems serve hot water system cylinders because the response may be too slow to enable effective compensation. Here it may well be best to use separate, condensing, direct-gas-fired water heaters or point-of-use devices.

Care is also needed where fan convectors etc. require minimum flow temperatures, although in this case limited amounts of compensation may sometimes be possible.

Air-handling units (AHUs) can be served from compensated systems. However, they will require a second stage of heating control, to reset the compensation control temperature if the water is not hot enough to meet the demand from the AHU. In the past this would have been difficult, but modern BMS controls and communications can do it relatively easily. The amount of compensation may need limiting, to enable a sufficiently rapid response.

Where secondary circuits need to be compensated independently, to allow for loads requiring different temperatures, mixing valves will need to be used and boilers should be directly compensated to a temperature slightly higher than the warmest secondary-circuit requirement.

### *Compensating and shutting down secondary circuits*

It is common to find compensated secondary circuits for radiators etc. in commercial and public buildings; however, they are often not set up for optimum control. Sometimes reset is included from space temperature, but often this is corrupted by poor sensor location or owing to supplementary local controls such as thermostatic radiators valves (TRVs). High ambient temperature shutdown control can be very effective, by switching off the circuit once the ambient temperature reaches the balance point for the building.

### *Direct compensation/temperature reset of heat pumps and chillers*

The efficiency of heat pumps and chillers is directly related to operating temperatures, so energy can be saved by promoting effective direct compensation/reset with chilled water temperatures raised and hot water temperatures reduced where practicable. This type of control is relatively common for heat pumps but rarely used for chillers. Chilled water temperature reset may not be practicable where there are process or dehumidification loads that require lower chilled water temperatures with reset, but this does not apply in most buildings. If necessary, the reset can also be overridden via a second stage of cooling control.

Where heat pumps serve hot water system storage cylinders, interlocks to override the reset must be incorporated, in a manner similar to that in systems which have directly compensated condensing boilers.

### *Emitter/space-temperature control*

Emitter control ranges from local TRVs and thermostats to direct digital control (DDC) with full demand-based control of boilers etc. There is great potential for energy savings from the promotion of more advanced forms of space-temperature control combined with integrated demand-based control. Systems are available from domestic systems through to full BMS, but current uptake is low.

TRVs and thermostats can provide acceptable space-temperature control of radiators, but more advanced controls are normally more accurate and provide more stable comfort conditions with lower energy use. Low-cost controls are available for radiators, under-floor heating, etc., with electrothermal or motorised actuators and time-proportioning operation. Air-conditioning terminal units, fan coil units, etc., should incorporate modulating control to avoid cold draughts and unstable operation.

### *Zone control*

In the past, it was good practice to control different zones of a building according to occupancy, temperature requirements and so on, so specifications were incorporated into many EU building code compliance requirements and related standards. Now modern controls allow individual emitters to be controlled for occupancy, temperature, etc., and for the control of the main plant to be demand-based. The results can be far more energy efficient than zoning, although some national building regulations have not caught up. This can lead to problems where a regulatory insistence on using zone valves conflicts with the more modern demand-responsive solution, e.g. with three-port zone valves compromising the control of the variable-flow systems operation. Work may be required here to develop model solutions and lobby policymakers. Window contacts that allow “set points” to be set and the room status in eco – or frost mode to be managed while the window is open are complementary to zone controls.

### *Ventilation*

Better control of ventilation offers benefits in terms of both air quality and energy efficiency. Ventilation is often poorly related to demand, leading to excessive ventilation and energy wastage in many cases and poor air quality in others. Indeed, both can often occur in the same building, with ventilation rates too high overall, but too low to accommodate peak occupancy in particular spaces. With buildings becoming more airtight to reduce uncontrolled infiltration and reduce energy requirements, effective control of ventilation is becoming increasingly important.

The incidence of high $CO_2$ levels in schools – both new and old – and its effect on alertness have been publicised recently. In many other buildings, although air quality has often improved as a result of smoking bans, $CO_2$ and pollutant levels can also be high. There is great potential for energy savings using demand-based ventilation control, in particular using $CO_2$ detection (which has become quite common in public and commercial buildings and is relatively low cost) and presence detection, which can be effective in toilets and bathrooms, for example, varying extraction rates in relation to the levels of use. Better control of natural ventilation also offers major improvements and savings.

### *Air conditioning/comfort cooling*

Air-conditioning systems often operate very wastefully, essentially because there is much more to go wrong (e.g. heating fighting against cooling). Numerous systems are poorly controlled, or difficult to control owing to poor configuration, e.g. with incorrectly sized control valves that influence the stability of systems. Management and maintenance can also leave a lot to be desired. Provided there is nothing fundamentally wrong with systems, they can often be set up to work more efficiently and effectively, sometimes with extraordinary results, reducing consumption by factors of two or more.

More effective heat recovery via thermal wheels and heat exchangers generally is easier to control than with dampers, which are rarely appropriately sized. More effective monitoring strategies to identify unstable systems etc. are required for ongoing system operation.

Many central systems incorporate AHUs and terminal units with heating and cooling coils using low-temperature hot water and chilled water. These often operate in accordance with well-established control principles common 20−30 years ago. Meanwhile, technology has moved on:

- variable speed fans are now common and have greater efficiencies, often stimulated by regulations; they also allow $CO_2$ control to be incorporated
- modern fan coil units are significantly more efficient than their predecessors and offer variable-flow operation in response to load
- variable refrigerant flow (VRF) systems have advanced significantly, offering functions such as heat recovery from comfort cooling that can be used to displace heating requirements and to heat domestic hot water. Controls packaged with VRF systems can be restrictive for some uses, but they have generally advanced in line with the systems they are controlling
- many items have integral controllers, with network interfaces to BMS using standard communications protocols such as BACnet.

Twenty years ago, it was common to provide variable air volume (VAV) systems for internal areas in offices with high heat gains. Over the years, heat gains have significantly reduced in some offices, owing to more efficient PCs/displays and lighting. As a result, some areas can become over-cooled at minimum air volumes, which may have led to additional use of heating. However, a review of the system and its control may allow energy savings by reducing central cooling instead. In one building known to the authors of this report, the use of chillers has been eliminated apart from in very hot weather.

Larger projects generally have BMS with communicating control systems from terminal units through to the main plant. While there is significant scope to improve performance with good commissioning and ongoing optimisation, the basic systems are normally in place. More difficulties occur where the original system is inappropriate or has been illogically modified over the years.

# Appendix B: Examples of improvements that can be achieved by the application of continuous commissioning

This appendix includes some examples of the improvements that can be achieved by the application of continuous commissioning to building services engineering and building automation technology. Figure B1 shows the savings that were made as a result of real-time monitoring of a fan motor and then using the existing controls to set back the fan overnight.

Figure B2 is taken from the energy monitoring software at Charing Cross Hospital in London and shows daily half-hourly consumption of an air-handling unit (AHU) before and after control adjustment. The AHU was set back at night when the patients were sleeping and there was minimal circulation around the wards. It was set back further at night time because the air volumes were still higher than necessary. The monitoring and targeting system enabled validation of the savings.

Figure B3 is taken from the energy monitoring software of a site participating in Toyota GB's carbon and energy management pilot scheme, which took place in 2008. The programme won an award in 2011 from the UK Chartered Institution of Building Services Engineers (CIBSE). As a result of the programme, Toyota sites are realising energy savings of 20% annually.

The figure demonstrates the importance of not only achieving savings but having a process in place to be able to sustain them year on year. In this case continuous commissioning provided a scenario where the building manager had the technical tool (i.e. the energy monitoring software), the motivation and the know-how (from the training and mentoring) to spot the fact that the controls on the energy equipment were no longer being properly used and consumption was erratic instead of reflecting occupancy hours (0700 to 1800). The building manager was urged to investigate the

**Figure B1. Benefits from real-time monitoring of a fan motor, before and after setting back the fan overnight (M&T = monitoring and targeting).**

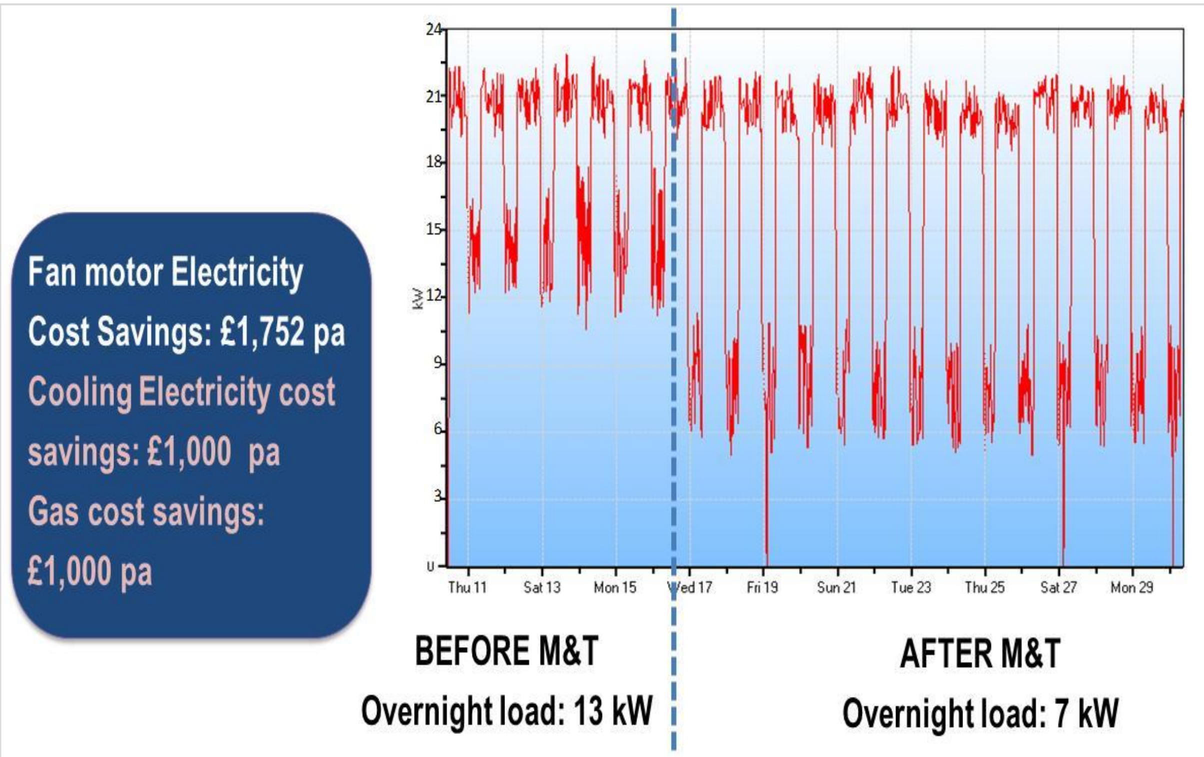
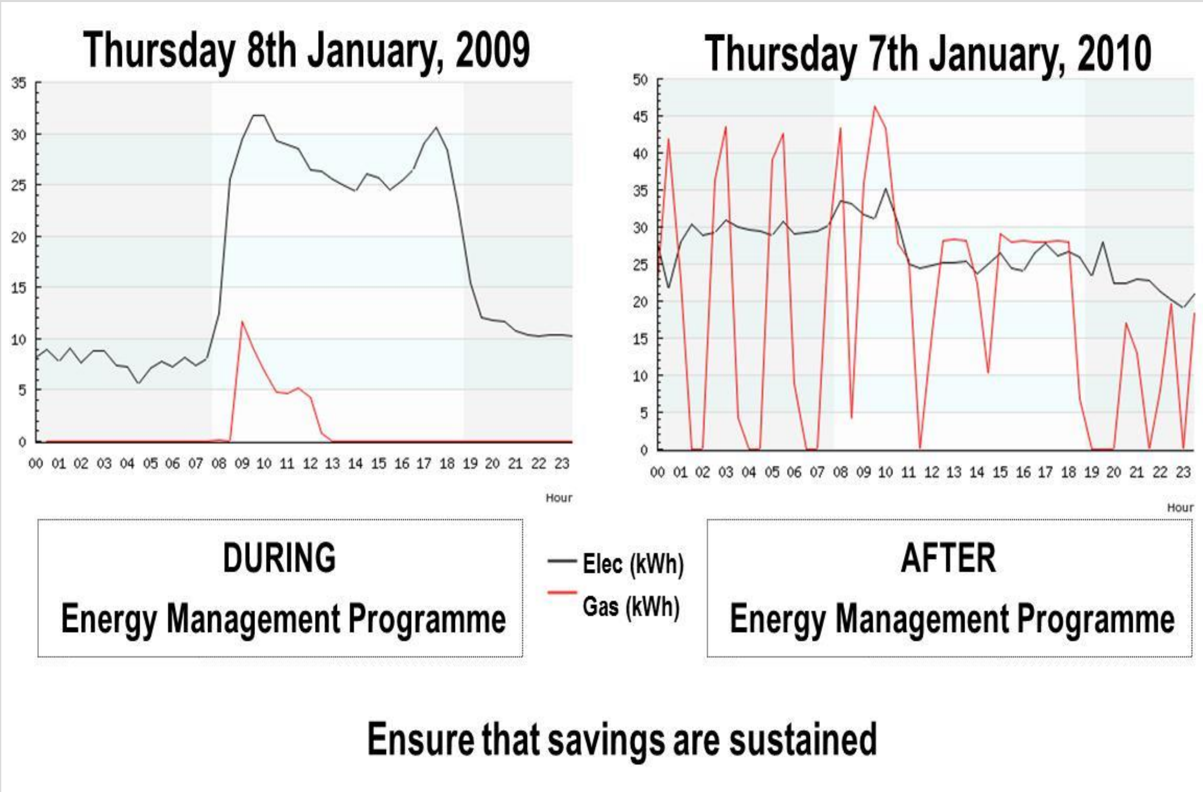


**Figure B2. Energy consumption before and after imposition of an energy management programme at Charing Cross Hospital, London, UK.**




cause of the change and engage the facilities team once again to ensure that the controls were re-commissioned and checked more often.

The first step in the energy awareness campaign centred around a one-day carbon and energy management workshop. The workshop was offered to each site's management team, maintenance staff and employees and focused on providing practical advice and training on energy.

The actions that resulted in the 26% saving in energy consumption included:

- training and awareness workshop
- resetting of outside lights
- email alerting staff
- lighting instructions to cleaner
- switching off personal computers (PCs) overnight and not waking up them automatically
- switching off immersion heater
- setting up and powering down monitors
- switching off two projectors
- timers on coffee and water dispensers.

Figure B4 shows before and after weekly energy consumption at a highly serviced, air-conditioned laboratory building at Imperial College in London, UK. Annual savings were calculated to be £50 000.

Prior to implementation of the energy management programme, the equipment rooms required 24-hour ventilation for cooling purposes, while the main laboratories required cooling and ventilation only during working hours. Consequently, equipment rooms were imposing 24-hour operation on

**Figure B3. Energy savings achieved after an energy awareness campaign at Toyota GB sites.**

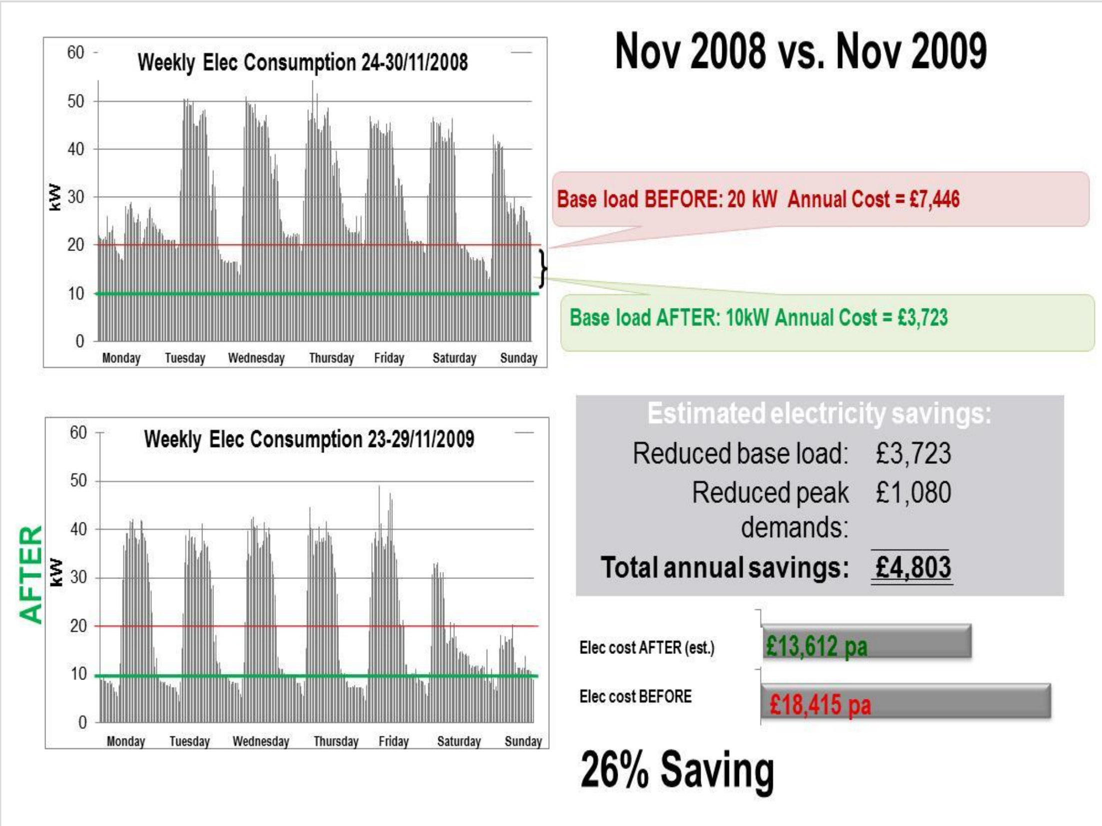
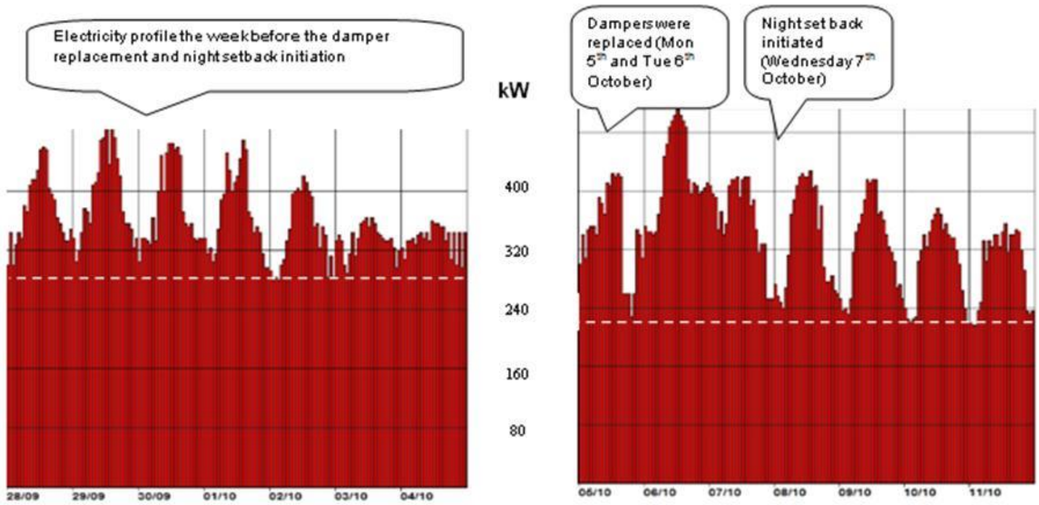



**Figure B4. Energy savings achieved in a laboratory building at Imperial College, London, UK.**




| | kWh | Cost £ | CO2 Tonnes | Time Schedule | |
|---|---|---|---|---|---|
| Current savings | 229,320 | 19,607 | 122.5 | 10pm to 7am | Mon - Sun |
| Add 4 hrs per day | 43,680 | 3,735 | 23.3 | 6pm to 10pm | Mon-Fri |
| Add weekends | 28,080 | 2,401 | 15.0 | 7am - 6pm | Sat- Sun |
| Reduce daytime P set point | 218,400 | 18,673 | 116.6 | 40 kW | |
| Add heating and cooling savings | 70,175 | 6,000 | 37.5 | | |
| | **589,655** | **50,416** | **315** | | |

the systems for both areas. In order to implement night set-back, it was necessary to separate the ventilation to the equipment rooms from the main laboratories during silent hours, converting the existing balancing dampers to motorised dampers. The new motorised dampers resolved the balancing and pressure differential problems by linking them to pressure transducers across the doors of the laboratories. The new control strategy included:

- differential pressure sensing between rooms
- motorising the existing balancing dampers
- commissioning the system to provide reduced air flow during silent hours in accordance with the heat gains of the rooms while maintaining the required pressure differentials between rooms.

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