The impact of the revision of the EPBD on energy savings from the use of building automation and controls

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Glossary

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.
BACnet	A communications protocol for building automation and control networks.
BACS	building automation and control systems
BACS class	The energy performance class (A to D) of a BACS as defined in EN15232
BACS factor	The relative energy impact of a given BACS class relative to class C (which has a BACS factor of 1) as defined in EN15232
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.
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
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.
Emitter	A device that emits heat or cold, such as a radiator or fan coil.
EN15232	European standard *EN 15232:2017. Energy performance of buildings. Impact of building automation, controls and building management*, Comité European de Normalisation
EPBD	Energy Performance of Buildings Directive (of which the former version is Directive 2010/31/EU and the latest recast version which amends it is Directive (EU) 2018/844 of the European Parliament and of the Council)
EU	European Union
eu.bac	European Building Automation Controls Association
European standard	A *standard* adopted by a European standardisation organisation.
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
1. IZC	Individual zone control
MFH	Multi-family housing.

Occupancy sensor	A device that detects whether people are present or absent from a space.
Optimiser	A dedicated *controller* for *optimum start/stop*. Note, in the near future optimiser will also refer to controllers that can optimise the use of energy e.g. optimisation of self-consumption.
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.
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.
SFH	Single family housing.
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.
Technical building system (TBS)	means technical equipment for the heating, cooling, ventilation, hot water, lighting or for a combination thereof, of a building or building unit.
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.
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

The recast Energy Performance of Buildings Directive (EPBD)[1] issued in 2018 aims to further improve the energy efficiency of buildings. The directive recognizes that effective control of technical building systems (space heating, space cooling, sanitary hot water, ventilation and lighting) is an essential element of overall system efficiency and holds a significant and cost-effective energy saving potential. While its predecessor (the 2010 version) only included rather indirect or ambiguous encouragement to improve building energy performance through better control of technical building systems, the revised Directive addresses this deficiency by adding a number of policy measures that target better monitoring and control of building energy systems.

BACS policy measures in the recast EPBD

Explicitly, the recast EPBD includes a number of new provisions that concern the deployment and use of Building Automation and Control Systems (BACS). In summary, these are:

- Mandatory requirements for installation and retrofit of BACS in non-residential buildings (existing and new) with effective rated output of over 290 kW, by 2025 *(within the amended articles 14 and 15)*
- Incentives for installation of continuous electronic energy performance monitoring and effective HVAC controls in existing and new multifamily buildings *(within the amended articles 14 and 15)*
- Requirements for the installation of individual room temperature controls such as TRVs and IZC in new buildings and alongside the replacement of heat generators in existing buildings *(within the amended article 8)*
- Non-residential and residential buildings equipped with BACS and electronic monitoring, respectively, are exempted from physical inspections of Heating and Air-Conditioning Systems *(within the amended articles 14 and 15)*
- Optimization of performance under typical or average (real-life) part load operating conditions including dynamic hydraulic balancing *(mentioned in the Recitation)*
- Reinforced requirements on optimizing the performance of technical building systems (TBS) i.a. with controls *(within the amended article 8)*
- Definition of BACS according to the European Standards in the Directive *(within the amended article 2)*

Impact analysis and scenarios

The accompanying Impact Assessment to the recast EPBD did not explicitly assess the impact of these measures; rather they were bundled into the overall impacts reported for the recast Directive. However, it is important for policy makers and others with responsibility for implementing the Directive at the Member State level to understand the contribution that these new measures will bring to the overall energy savings target, as this helps to clarify the relative importance of these actions in the ensemble of measures put forward in the revised EPBD.

The current study presents a detailed analysis of the expected impacts associated with the implementation of the recast EPBD BACS measures. It makes use of a detailed bottom-up simulation

[1] DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

tool, developed specifically for the purpose, to assess the contributions to energy savings made by BACS measures under three scenarios:

- The ***EPBD compliant*** scenario (where all the BACS measures are appropriately implemented)
- The ***EBPD compliant without BACS*** scenario (where the BACS policy measures are not implemented but all other EPBD measures are)
- A ***Frozen BACS*** scenario, where the BACS policy measures are not implemented and the BACS energy performance remains the same, while the other EPBD measures are implemented.

These scenarios are projected from 2018 to 2050, i.e. the same period assessed in the official recast EPBD impact assessment (Ecofys 2016).

It should be noted that the *EPBD compliant* scenario is identical to the central "Agreed Amendments" scenario in the EPBD impact assessment which results in very substantial energy savings in the EU building stock to 2050. It assumes an array of measures, including those that will substantially improve the efficiency of the building fabric and the BACS measures contribute to the net savings delivered.

Under the *EBPD compliant without BACS* scenario all non-BACS measures are implemented just as in the EPBD *Agreed Amendments* scenario, but the BACS measures from the recast EPBD are not implemented; rather the BACS performance evolves as would be expected under the previous (non-recast) version of the EPBD. In this sense the title of the scenario is something of a misnomer because the scenario is only compliant with the parts of the recast EPBD that do not address BACS; in the case of BACS it assumes the same progression as would have been expected had the EPBD not been recast. This scenario is necessary to isolate the impact of the BACS related policy measures within the recast EPBD from the other policy measures.

In the *Frozen BACS* scenario the energy performance of the BACS systems used remains constant i.e. at exactly the same levels as were exhibited at the beginning of the scenario period, 2018.

Thus, with regard to the control of building energy systems the *Frozen BACS* scenario is a no-improvement case, the *EBPD compliant without BACS* scenario is a Business as Usual case, and the *EPBD compliant* scenario is the case where the new BACS policy measures in the recast EPBD are implemented as required under the Directive. The impact of the recast EPBD BACS measures (in terms of energy, CO_2 emissions and economic impacts) is thus the difference between the *EPBD compliant without BACS* scenario and the *EPBD compliant* scenario.

Methodology

To analyse these scenarios a detailed bottom-up Excel model was developed to simulate the European building stock. Just like the recast EPBD's impact assessment It is primed with detailed building stock data and energy data from the official statistics as reported in the EU Building Stock Observatory, which is a database established by the DG Energy to monitor the energy performance of buildings across Europe. The model projects the evolution of the building stock forward in time using exactly the same assumptions as reported in the recast EPBD impact assessment so that the floor area by building type, the choice of fuels/energy sources, the fabric materials and composition, the usage profiles, the type of technical building systems and the efficiency of the technical building systems all evolves in line with the official impact assessment. The innovation of the current study is to explicitly analyse and overlay the evolution of the energy performance of the building energy system controls (the BACS) onto this progression and then to examine how the evolution in the BACS performance would vary were the measures in the EPBD regarding BACS not to be implemented, while all other measures are.

The approach used is to apply the simplified BACS factors from the European standard EN15232. This classifies BACS into energy performance classes, from D (lowest energy performance) to A (highest energy performance). Under EN15232 average energy performance indices (BACS factors) are associated with these classes and can be applied to scale the energy consumption of the technical building systems that are being controlled. Thus, a class C BACS will have a BACS factor of 1, whereas a class D will be higher than 1 and class B or A lower than 1. These BACS factors have been derived by analysis of a very extensive set of detailed building energy performance simulations, based on the known properties of control systems and the technical building systems they control. The BACS energy performance classes, and associated BACS factors, are associated with step changes in the functionality of the BACS in question. E.g. from a simple manually controlled light switch (class D) to lighting which is controlled by presence detectors and is self-dimming in response to rising daylight levels (class A). Similar functionality descriptions apply to the BACS classes and factors applicable to each technical building system and all the solutions currently used to deliver the service. In addition, the BACS factors are calibrated as a function of the type of building being considered (e.g. single-family housing, multi-family housing, offices, education buildings, retail, etc.). Thus, overall there is a very extensive array of building types, technical building system solutions, and BACS functionality levels that can be applied – each combination of which gives rise to a specific BACS factor under EN15232.

The simulation model used in this study has been set up to treat all of these combinations and project them forward in time in response to the stimuli to evolution in BACS functionality inherent in each of the three scenarios. The starting point, i.e. the distribution of BACS energy performance class per TBS solution and building type, was determined by applying extensive survey information compiled for the study by eu.bac members in conjunction with earlier data reported in the literature.

While the *Frozen BACS* scenario is straightforward in that the distribution in BACS energy classes do not change over the course of the scenario period, for the other two scenarios the distribution of BACS by energy performance class is expected to improve over time. To estimate the expected trends under the *EPBD compliant scenario without BACS* scenario an analysis was conducted of historic improvement rates per BACS renewal event and these are then assumed to continue into the future.

For the *EPBD compliant* scenario the impact of the measures in the recast EPBD is overlaid over these trends in a manner that is wholly consistent with the EPBD requirements. In general, this roughly equates to moving to class B BACS functionality for BACS renewal/fresh installation events whenever such events are in response to a specific policy measure in the recast EPBD, but otherwise adopting the same evolution as in the *EPBD compliant without BACS* scenario.

The energy impacts of these trends are derived by applying the BACS factor evolution to the energy consumption of each technical building system per the approach described above. The fuel mix, energy prices, primary energy factors and CO_2 emissions factors assumption are fully aligned with those used in the official EPBD impact assessment.

Energy savings and other impacts from improved BACS under the recast EPBD

Overall, the analysis finds that appropriate implementation of the BACS related policy measures in the recast EPBD will save 14% of total building primary energy consumption by 2038.

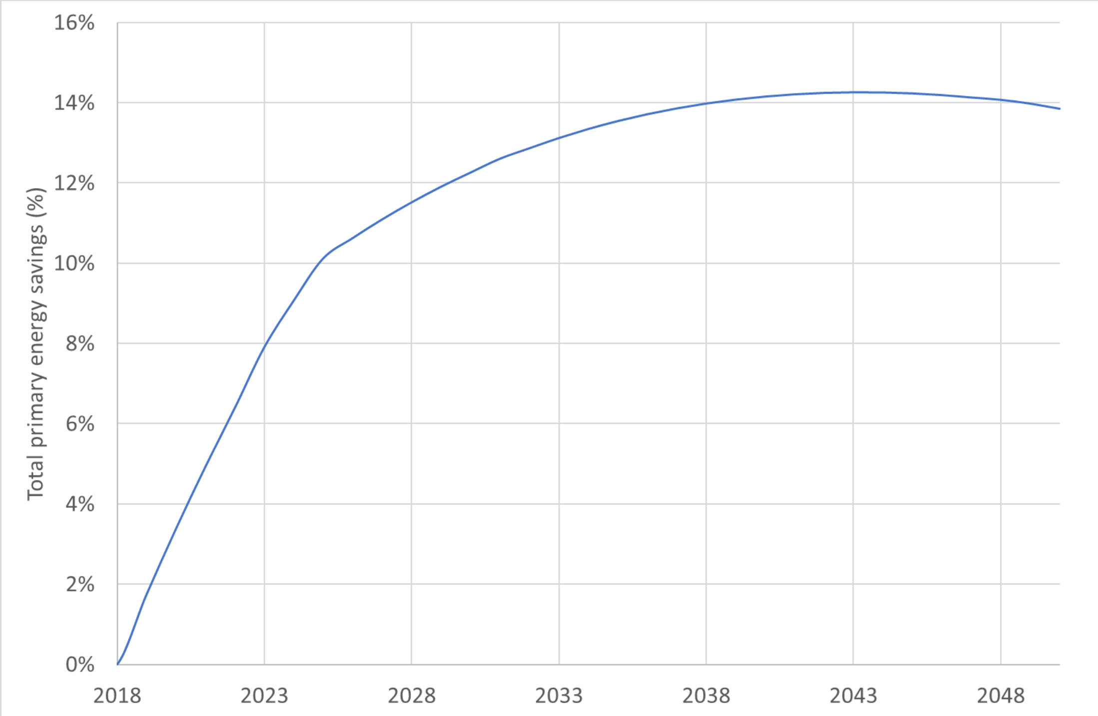


Figure ES1 – Total primary energy savings for all buildings for the *EPBD compliant* scenario compared to the *EPBD compliant without BACS* scenario

This gives rise to over 450 TWh of annual final energy savings (Figure ES2) peaking in 2035 despite this occurring in the context of a sharply declining overall building stock energy consumption due to the ensemble of the recast EPBD policy measures. Figure ES3 shows the general trends in EU building stock energy consumption under the three scenarios.

In terms of CO_2 emissions, the *EPBD compliant* scenario leads to annual savings that peak at 64 Mt in 2030.

The investments necessary to deliver these BACS rise sharply to an annual peak of ~€7.4 billion in 2022 but decline rapidly thereafter. The value of the energy bill savings triggered by these investments rises sharply to about €32 billion in 2025 and then more gradually to a peak of €36 billion in 2035 before gently declining thereafter. Overall the value of the energy savings far exceeds the cost of the investments. Over the whole scenario period the value of energy savings exceeds the value of investments by a factor of 9 (comprised of a factor of 8.1 for residential buildings and 10.4 for non-residential buildings).

Implications

The analysis reported in this study complements the formal impact assessment to the recast EPBD by adding missing detail on the expected impact of the BACS-related policy measures. It shows that an important part of the energy saving impact of the recast EPBD can be attributed to the policy measures that concern the accelerated deployment of improved building automation and controls; which justifies the additional focus given to them in the recast EPBD. Nonetheless although energy savings of over 14% of total primary energy savings for the building stock are associated with the full implementation of these measures, significantly deeper energy savings could be achieved from using even higher performance BACS i.e. those consistently at the class A energy performance level.

Of course, in order to leverage the significant energy saving potential of BACS an appropriate transposition and implementation of the relevant EPBD provisions by Member States is crucial.

An appropriate implementation of the BACS related requirements in the recast EPBD will contribute significantly to cost-effective decarbonization of the EU building stock and sector coupling – and hence to successful energy transition.

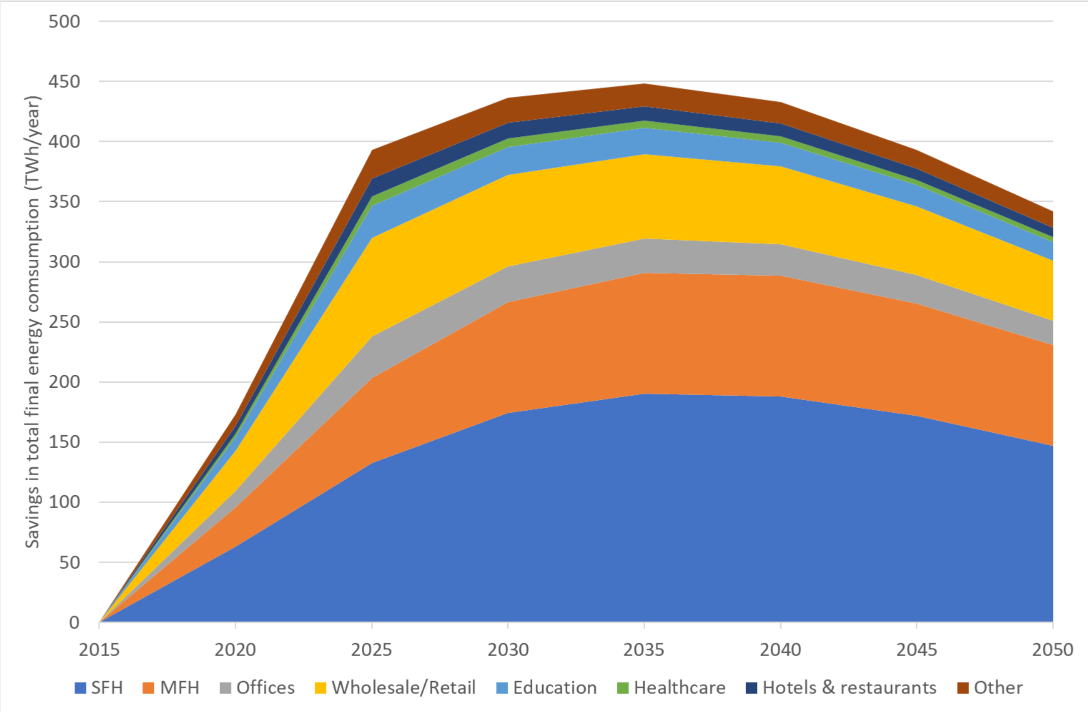


Figure ES2 – Savings in total final energy consumption of EU buildings for the *EPBD compliant* compared to the *EPBD compliant without BACS* scenario

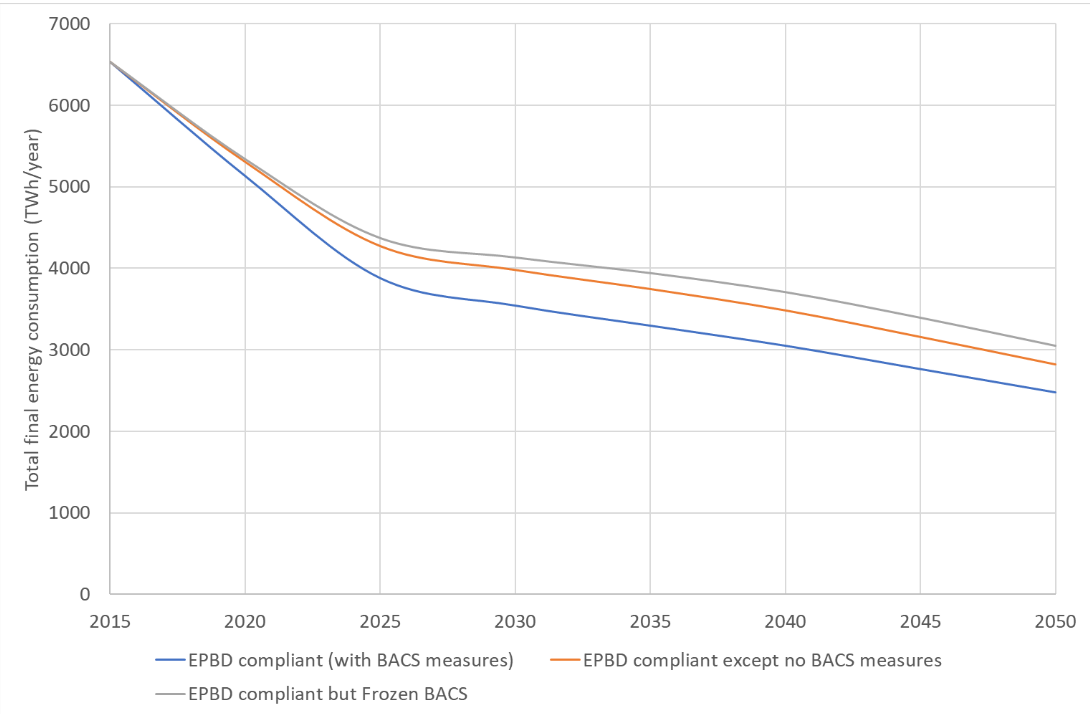


Figure ES3 – Total final energy consumption for EU buildings by scenario

1. Introduction

Buildings are widely reported to consume 40% of all energy in Europe. 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.

In the summer of 2018 the EPBD was revised (recast) and new measures introduced which partially address this opportunity and redress some of the earlier gaps with regard to the energy savings from building automation and control systems.

This report presents the findings of an analysis commissioned by the European Building Automation Controls Association (eu.bac) to examine the impact of the new EPBD measures concerning BACS on the energy consumption of Europe's buildings. This is necessary because many of the measures were introduced late in the EPBD revision process and hence were not explicitly modelled in the EPBD's impact assessment. The intention of this this analysis is to examine and help clarify the expected benefits from full implementation of these measures and the consequences of not doing so.

Context of why BACS are now being addressed

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.

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.

[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.

Current technologies and barriers to their implementation

Modern building automation control systems (BACS) brings the electromechanical hardware of sensors, valves and 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 can go 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. 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 in recent years and continues to grow, 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 BACS is projected to rise from ~26% of all service sector floor area today to 40% by 2028 even in the absence of the recast EPBD policy measures. In the residential sector, penetration of HEMS is projected to rise from a few percent of homes today to ~ 40% by 2034 without additional intervention (WSE 2014).

Nonetheless, these levels are considerably below the full potential and illustrate why additional policy measures are justified and were added in the recast EPBD.

2. Provisions in the revised EPBD that concern BACS

The recast energy performance in buildings directive (EPBD)[3] includes a number of new provisions that concern the deployment and use of BACS. In summary these are:

- Mandatory requirements for installation and retrofit of Building Automation and Control Systems (BACS) in non-residential buildings (existing and new) with effective rated output of over 290 kW, by 2025 *(within the amended articles 14 and 15)*
- Incentives for installation of continuous electronic energy performance monitoring and effective HVAC controls in existing and new multifamily buildings *(within the amended articles 14 and 15)*
- Requirements for the installation of individual room temperature controls such as TRVs and IZC in new buildings and alongside the replacement of heat generators in existing buildings *(within the amended article 8)*
- Non-residential and residential buildings equipped with BACS and electronic monitoring, respectively, are exempted from physical inspections of Heating and Air-Conditioning Systems *(within the amended articles 14 and 15)*
- Optimization of performance under typical or average (real-life) part load operating conditions including dynamic hydraulic balancing *(mentioned in the Recitation)*
- Reinforced requirements on optimizing the performance of TBS i.a. with controls *(within the amended article 8)*
- Definition of BACS according to the European Standards in the Directive *(within the amended article 2)*

In addition, the recast EPBD also introduces a smart readiness indicator (SRI) which, while voluntary at the Member State level, should have some important impacts for BACS; however, the assessment of the impact of the SRI depends on a great many variables and is beyond the scope of the current investigation. Rather it is being assessed in a separate independent process on behalf of the European Commission[4].

2.1 Specific EPBD text concerning BACS

The following text related to BACS is included in the recast EPBD:

Recitation clauses:

"(21) The installation of self-regulating devices in existing buildings for the separate regulation of the temperature in each room or, where justified, in a designated heated zone of the building unit should be considered where economically feasible, for example where the cost is less than 10 % of the total costs of the replaced heat generators.

(30) The smart readiness indicator should be used to measure the capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grid and to improve the energy efficiency and overall performance of buildings. The smart readiness indicator should raise awareness amongst building owners and occupants of the value behind building automation and electronic monitoring of technical

[3] DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency
[4] See https://smartreadinessindicator.eu/

building systems and should give confidence to occupants about the actual savings of those new enhanced-functionalities. Use of the scheme for rating the smart readiness of buildings should be optional for Member States.

(35) According to the Commission's impact assessment, provisions concerning the inspections of heating systems and air-conditioning systems were found to be inefficient because they did not sufficiently ensure the initial and continued performance of those technical systems. Even cheap energy efficiency technical solutions with very short payback periods, such as hydraulic balancing of the heating system and the installation or replacement of thermostatic control valves, are insufficiently considered today. The provisions on inspections should be amended to ensure a better result from inspections. Those amendments should place the focus of inspections on central heating systems and air-conditioning systems, including where those systems are combined with ventilation systems. Those amendments should exclude small heating systems such as electric heaters and wood stoves when they fall below the thresholds for inspection pursuant to Directive 2010/31/EU as amended by this Directive.

(36) When carrying out inspections and in order to achieve the intended building energy performance improvements in practice, the aim should be to improve the actual energy performance of heating systems, air-conditioning systems and ventilation systems under real-life use conditions. The actual performance of such systems is governed by the energy used under dynamically varying typical or average operating conditions. Such conditions require at most times only a part of the nominal output capacity, and therefore inspections of heating systems, air-conditioning systems and ventilation systems should include an assessment of the relevant capabilities of the equipment to improve system performance under varying conditions, such as part load operating conditions.

(37) Building automation and electronic monitoring of technical building systems have proven to be an effective replacement for inspections, in particular for large systems, and hold great potential to provide cost-effective and significant energy savings for both consumers and businesses. The installation of such equipment should be considered to be the most cost-effective alternative to inspections in large non-residential and multi-apartment buildings of a sufficient size that allow a payback of less than three years, as it enables action to be taken on the information provided, thereby securing energy savings over time. For small-scale installations, the documentation of the system performance by installers should support the verification of compliance with the minimum requirements laid down for all technical building systems.

(40) Without prejudice to the Member States' choice to apply the set of standards, related to energy performance of buildings, developed under Commission mandate M/480 to the European Committee for Standardisation (CEN), the recognition and promotion of those standards across the Member States would have a positive impact on the implementation of Directive 2010/31/EU as amended by this Directive."

Amendments to the main Articles:

"(1) Article 2 Definitions is amended as follows:

(a) point 3 is replaced by the following:

'3. "technical building system" means technical equipment for space heating, space cooling, ventilation, domestic hot water, built-in lighting, building automation and control, on-site electricity generation, or a combination thereof, including those systems using energy from renewable sources, of a building or building unit;';

(b) the following point is inserted:

'3a. "building automation and control system" means a system comprising all products, software and engineering services that can support energy efficient, economical and safe operation of technical

building systems through automatic controls and by facilitating the manual management of those technical building systems;';

'*Article 8 Technical building systems, electromobility and smart readiness indicator*

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.

System requirements shall be set for new, replacement and upgrading of technical building systems and shall be applied in so far as they are technically, economically and functionally feasible.

Member States shall require new buildings, where technically and economically feasible, to be equipped with self-regulating devices for the separate regulation of the temperature in each room or, where justified, in a designated heated zone of the building unit. In existing buildings, the installation of such self-regulating devices shall be required when heat generators are replaced, where technically and economically feasible.

9. Member States shall ensure that, when a technical building system is installed, replaced or upgraded, the overall energy performance of the altered part, and where relevant, of the complete altered system, is assessed. The results shall be documented and passed on to the building owner, so that they remain available and can be used for the verification of compliance with the minimum requirements laid down pursuant to paragraph 1 of this Article and the issue of energy performance certificates. Without prejudice to Article 12, Member States shall decide whether to require the issuing of a new energy performance certificate.

10. The Commission shall, by 31 December 2019, adopt a delegated act in accordance with Article 23, supplementing this Directive by establishing an optional common Union scheme for rating the smart readiness of buildings. The rating shall be based on an assessment of the capabilities of a building or building unit to adapt its operation to the needs of the occupant and the grid and to improve its energy efficiency and overall performance.

In accordance with Annex Ia, the optional common Union scheme for rating the smart readiness of buildings shall:

(a) establish the definition of the smart readiness indicator; and

(b) establish a methodology by which it is to be calculated.

11. The Commission shall, by 31 December 2019, and after having consulted the relevant stakeholders, adopt an implementing act detailing the technical modalities for the effective implementation of the scheme referred to in paragraph 10 of this Article, including a timeline for a non-committal test-phase at national level, and clarifying the complementary relation of the scheme to the energy performance certificates referred to in Article 11.

That implementing act shall be adopted in accordance with the examination procedure referred to in Article 26(3)."

"'Article 14 Inspection of heating systems

1. Member States shall lay down the necessary measures to establish regular inspections of the accessible parts of heating systems or of systems for combined space heating and ventilation, with an effective rated output of over 70 kW, such as the heat generator, control system and circulation pump(s) used for heating buildings. The inspection shall include an assessment of the efficiency and sizing of the heat generator compared with the heating requirements of the building and, where *relevant, consider the capabilities of the heating system or of the system for combined space heating and ventilation to optimise its performance under typical or average operating conditions.*

Where no changes have been made to the heating system or to the system for combined space heating and ventilation or to the heating requirements of the building following an inspection carried out pursuant to this paragraph, Member States may choose not to require the assessment of the heat generator sizing to be repeated.

2. Technical building systems that are explicitly covered by an agreed energy performance criterion or a contractual arrangement specifying an agreed level of energy efficiency improvement, such as energy performance contracting, or that are operated by a utility or network operator and therefore subject to performance monitoring measures on the system side, shall be exempt from the requirements laid down in paragraph 1, provided that the overall impact of such an approach is equivalent to that resulting from paragraph 1.

3. As an alternative to paragraph 1 and provided that the overall impact is equivalent to that resulting from paragraph 1, Member States may opt to take measures to ensure the provision of advice to users concerning the replacement of heat generators, other modifications to the heating system or to the system for combined space heating and ventilation and alternative solutions to assess the efficiency and appropriate size of those systems.

Before applying the alternative measures referred to in the first subparagraph of this paragraph, each Member State shall, by means of submitting a report to the Commission, document the equivalence of the impact of those measures to the impact of the measures referred to in paragraph 1.

Such a report shall be submitted in accordance with the applicable planning and reporting obligations.

4. Member States shall lay down requirements to ensure that, where technically and economically feasible, non-residential buildings with an effective rated output for heating systems or systems for combined space heating and ventilation of over 290 kW are equipped with building automation and control systems by 2025.

The building automation and control systems shall be capable of:

(a) continuously monitoring, logging, analysing and allowing for adjusting energy use;

(b) benchmarking the building's energy efficiency, detecting losses in efficiency of technical building systems, and informing the person responsible for the facilities or technical building management about opportunities for energy efficiency improvement; and

(c) allowing communication with connected technical building systems and other appliances inside the building, and being interoperable with technical building systems across different types of proprietary technologies, devices and manufacturers.

5. Member States may lay down requirements to ensure that residential buildings are equipped with:

(a) the functionality of continuous electronic monitoring that measures systems' efficiency and informs building owners or managers when it has fallen significantly and when system servicing is necessary; and

(b) effective control functionalities to ensure optimum generation, distribution, storage and use of energy.

6. Buildings that comply with paragraph 4 or 5 shall be exempt from the requirements laid down in paragraph 1.

Article 15 Inspection of air-conditioning systems

1. Member States shall lay down the necessary measures to establish regular inspections of the accessible parts of air-conditioning systems or of systems for combined air-conditioning and ventilation, with an effective rated output of over 70 kW. The inspection shall include an assessment of the efficiency and sizing of the air-conditioning system compared with the cooling requirements of the building and, where relevant, consider the capabilities of the air -conditioning system or of the system for combined air-conditioning and ventilation to optimise its performance under typical or average operating conditions.

Where no changes have been made to the air-conditioning system or to the system for combined air-conditioning and ventilation or to the cooling requirements of the building following an inspection carried out pursuant to this paragraph, Member States may choose not to require the assessment of the sizing of the air-conditioning system to be repeated.

Member States that maintain more stringent requirements pursuant to Article 1(3) shall be exempt from the obligation to notify them to the Commission.

2. Technical building systems that are explicitly covered by an agreed energy performance criterion or a contractual arrangement specifying an agreed level of energy efficiency improvement, such as energy performance contracting, or that are operated by a utility or network operator and therefore subject to performance monitoring measures on the system side, shall be exempt from the requirements laid down in paragraph 1, provided that the overall impact of such an approach is equivalent to that resulting from paragraph 1.

3. As an alternative to paragraph 1 and provided that the overall impact is equivalent to that resulting from paragraph 1, Member States may opt to take measures to ensure the provision of advice to users concerning the replacement of air-conditioning systems or systems for combined air-conditioning and ventilation, other modifications to the air-conditioning system or system for combined air-conditioning and ventilation and alternative solutions to assess the efficiency and appropriate size of those systems.

Before applying the alternative measures referred to in the first subparagraph of this paragraph, each Member State shall, by means of submitting a report to the Commission, document the equivalence of the impact of those measures to the impact of the measures referred to in paragraph 1.

Such a report shall be submitted in accordance with the applicable planning and reporting obligations.

4. Member States shall lay down requirements to ensure that, where technically and economically feasible, non-residential buildings with an effective rated output for systems for air-conditioning or systems for combined air -conditioning and ventilation of over 290 kW are equipped with building automation and control systems by 2025.

The building automation and control systems shall be capable of:

(a) continuously monitoring, logging, analysing and allowing for adjusting energy use;

(b) benchmarking the building's energy efficiency, detecting losses in efficiency of technical building systems, and informing the person responsible for the facilities or technical building management about opportunities for energy efficiency improvement; and

(c) allowing communication with connected technical building systems and other appliances inside the building, and being interoperable with technical building systems across different types of proprietary technologies, devices and manufacturers.

5. Member States may lay down requirements to ensure that residential buildings are equipped with:

(a) the functionality of continuous electronic monitoring that measures systems' efficiency and informs building owners or managers when it has fallen significantly and when system servicing is necessary, and

(b) effective control functionalities to ensure optimum generation, distribution, storage and use of energy.

6. Buildings that comply with paragraph 4 or 5 shall be exempt from the requirements laid down in paragraph 1.'."

The annexes to Directive 2010/31/EU are amended as follows:

"(1) Annex I is amended as follows:

(a) point 1 is replaced by the following:

'1. The energy performance of a building shall be determined on the basis of calculated or actual energy use and shall reflect typical energy use for space heating, space cooling, domestic hot water, ventilation, built-in lighting and other technical building systems.

The energy performance of a building shall be expressed by a numeric indicator of primary energy use in kWh/(m2.y) for the purpose of both energy performance certification and compliance with minimum energy performance requirements. The methodology applied for the determination of the energy performance of a building shall be transparent and open to innovation.

Member States shall describe their national calculation methodology following the national annexes of the overarching standards, namely ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1, developed under mandate M/480 given to the European Committee for Standardisation (CEN). This provision shall not constitute a legal codification of those standards.';

(b) point 2 is replaced by the following:

'2. The energy needs for space heating, space cooling, domestic hot water, ventilation, lighting and other technical building systems shall be calculated in order to optimise health, indoor air quality and comfort levels defined by Member States at national or regional level.

(2) The following Annex is inserted:

'ANNEX IA COMMON GENERAL FRAMEWORK FOR RATING THE SMART READINESS OF BUILDINGS

1. The Commission shall establish the definition of the smart readiness indicator and a methodology by which it is to be calculated, in order to assess the capabilities of a building or building unit to adapt its operation to the needs of the occupant and of the grid and to improve its energy efficiency and overall performance.

The smart readiness indicator shall cover features for enhanced energy savings, benchmarking and flexibility, enhanced functionalities and capabilities resulting from more interconnected and intelligent devices.

The methodology shall take into account features such as smart meters, building automation and control systems, self-regulating devices for the regulation of indoor air temperature, built-in home appliances, recharging points for electric vehicles, energy storage and detailed functionalities and the interoperability of those features, as well as benefits for the indoor climate condition, energy efficiency, performance levels and enabled flexibility.

2. The methodology shall rely on three key functionalities relating to the building and its technical building systems:

(a) the ability to maintain energy performance and operation of the building through the adaptation of energy consumption for example through use of energy from renewable sources;

(b) the ability to adapt its operation mode in response to the needs of the occupant while paying due attention to the availability of user-friendliness, maintaining healthy indoor climate conditions and the ability to report on energy use; and

(c) the flexibility of a building's overall electricity demand, including its ability to enable participation in active and passive as well as implicit and explicit demand response, in relation to the grid, for example through flexibility and load shifting capacities.

3. The methodology may further take into account:

(a) the interoperability between systems (smart meters, building automation and control systems, built-in home appliances, self-regulating devices for the regulation of indoor air temperature within the building and indoor air quality sensors and ventilations); and

(b) the positive influence of existing communication networks, in particular the existence of high-speed-ready in -building physical infrastructure, such as the voluntary 'broadband ready' label, and the existence of an access point for multi-dwelling buildings, in accordance with Article 8 of Directive 2014/61/EU of the European Parliament and of the Council (*).

4. The methodology shall not negatively affect existing national energy performance certification schemes and shall build on related initiatives at national level, while taking into account the principle of occupant ownership, data protection, privacy and security, in compliance with relevant Union data protection and privacy law as well as best available techniques for cyber security.

5. The methodology shall set out the most appropriate format of the smart readiness indicator parameter and shall be simple, transparent, and easily understandable for consumers, owners, investors and demand-response market participants."

3. Methodology

The aim of the study is to model the impact of the recast EPBD provisions for BACS to aim to determine the impact that the BACS measures would be expected to deliver assuming that they are fully respected. The recast EPBD was the subject of a general impact assessment (Ecofys 2016) that ran ahead of the development of the revised text. The impact assessment did not explicitly model the impact of the BACS measures but rather modelled the expected impact of the Directive as a whole – it is therefore not possible to determine from the impact assessment what impacts are directly attributable to BACS as opposed to any of the myriad other measures considered, such as the renovation of buildings, within the EPBD. Therefore, this study takes the overall impact assessment scenario for the recast EPBD, known as the "*Agreed Amendments*" scenario, which corresponds to a scenario where the measures speculated for the recast EPBD in 2016 are fully implemented, as its the reference scenario. It then aims to isolate the effect of the main BACS policy measures from that to determine their impacts. In this way it is possible to derive BACS related impacts which are consistent with the other anticipated impacts of the recast EPBD.

3.1 General approach

In order to respect the principle summarised above the modelling exercise took the impact assessment central EPBD impact case as its base case. A building stock model was developed that treats the EU building stock by region (and beneath that by Member State where data allows) and projects it forward through time. Where possible the model makes use of the same data sets used in the EPBD impact assessment and is structured in the same way. It also makes use of official and informal data gathered within the Commission's "EU Building Stock Observatory" database[5].

The basic approach is to model the EU building stock changes to be consistent with those simulated in the Impact Assessment's *Agreed Amendments* scenario but to do this in such a way that the impact of the BACS measures can be modelled and analysed in isolation of the other EPBD measures. This requires the following:

- the energy use of each technical building system (TBS) (heating, hot water, cooling, ventilation, lighting) to be modelled explicitly
- mapping of the BACS policy measures in the recast EPBD to changes in the performance of these TBS over time.

The historic energy used by each TBS is documented in the EU Building Stock Observatory data by type of fuel and building for each EU member state and the overall impact of the EPBD is determined for these in an aggregated sense (by region) within the impact assessment.

As, the EU Building Stock Observatory also reports the historic floor area of the building stock by type and member state it is possible to derive energy use per unit area (square metre) by TBS and fuel type and to project these forward in line with the assumptions in the impact assessment with regard to the evolution in floor area and energy consumption by fuel. The model established for this study is thus structured to replicate the evolution in both as reported in the impact assessment.

To determine the impact of BACS on the energy consumed by the TBSs the study applies the standard EN15232:2017 *Energy performance of buildings. Impact of building automation, controls and building management* (CEN 2017). This standard classifies the functionality of BACS for each TBS and also for the collective management of all TBS. Based on the functionality delivered EN15232 determines an average expected energy impact, a so-called BACS factor, which can be applied to weight the resulting

[5] See https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/eubuildings

energy consumption. For each TBS, and specific service related to that TBS, EN15232 defines BACS factors for four BACS energy performance functionality classes (from class D – the least energy efficient functional option – to class A – the most energy efficient functional option). Application of these BACS factors gives an average adjustment factor of the energy used by that BACS/TBS service combination relative to the class C functionality, which is considered to be the reference and hence to have a BACS factor of 1. Thus, class D functionality usually has a factor of > 1 (and hence increases the consumption relative to class C) and class B and A will usually have factors < 1 and hence decrease energy consumption relative to class C BACS functionality.

Establishing the BACS functionality baseline

Within the published literature there is only limited data available on the distribution of BACS functionality by BACS functionality per the A to D energy performance classes specified in EN15232. There is no data on this aspect in the Building Stock Observatory and BACS functionality is not surveyed by Member States, or other organisations. In WSE (2014) the author and colleagues made use of a variety of sources to estimate the distribution of BACS functionality by TBS, building type and region/country across the EU. These included expert interviews and assessment, data on the market value of the BACS market by country which was then adjusted to attain the expenditure per square metre over time, data on typical BACS expenditure per square metre per new build or major renovation, information on new build and renovation rates, information on the cost of BACS per unit area by type of solution, and the reference class C BACS as set out in the EN15232 standard. Triangulation of these sources enabled estimates of BACS costs per unit area by level of functionality to be mapped to data on average BACS expenditure per new build, renovation, or replacement in a manner which is reconciled with the other available evidence. The ECOFYS & WSE (2017) study built upon this by aligning BACS costs with those reported by industry and the Commission and also mapped out specific reference buildings with quite typical yet specific BACS solutions per base case building type considered.

The current study combines both of these approaches but also includes an important additional element – a survey of eu.bac members – to gather information on their experience of the distribution of BACS functionality (expressed in EN15232 A to D classes) by building type and locale across the EU. This survey compiled company specific estimates of the distribution of BACS by functionality class, per TBS (distinguished by: space heating, hot water, cooling, ventilation & AC control, lighting, as well as the overall technical home and building management) and by building type (distinguished by: single family homes, multi-family residences, offices, retail outlets, education, healthcare, hospitality, entertainment/other). Depending on the respondent the results were either reported for Europe as a whole or for specific countries. Some respondents reported data for all building types and others for some specific types. While the specific data is confidential the synthesis of the values reported reveals that across the EU as a whole eu.bac members find that: class C BACS functionality predominates, class D and B are the next most common and class A BACS are very rare. In consequence average BACS factors, where the BACS factor is weighted by the proportion of the building stock having each energy performance class for a given TBS service, tend to be slightly above 1 i.e. between class C and D but closer to class C than D. There is a modest tendency for non-residential buildings to have higher BACS functionality than residential buildings, but the above statement still applies to non-residential buildings too. It is important to remember that a certain proportion of the building stock has almost no BACS in place too. This outcome is perhaps to be expected as class C under EN15232 is approximately intended to correspond be the typical solution being installed today and thus there is a legacy of less efficient solutions in the existing building stock.

It is important to reflect on the implications of this distribution from an energy savings policy perspective. If a non-residential heating system with class D BACS functionality is upgraded to class C BACS functionality it will typically lower its energy consumption by ~ 30%. Upgrading from C to B will save ~ 23%, and from B to A ~ 29%; however, in absolute energy consumption terms the class D to C step saves more than the B to A step (about 67% more) thus while the savings are still very substantial with each upgrade in functionality the greatest rewards occur from eliminating the poorest control practice.

Modelling technical building systems

BACS may be designed to control specific technical building system types or elements, but can also be designed to control the ensemble of technical building systems. The recast EPBD directive makes it clear that the provisions that relate to technical building systems must also include the controls i.e. BACS. The BACS functionality applicable to TBS is set out by type of service provided in EN15232. Thus, for space heating distinctions are made between the services that concern heat generation, heat distribution and heat emission. Specifically, the following services are listed:

Table 1. Space heating services treated in EN15232

Section	Type of control service	Notes on the control scope and objectives
1.1	Emission control	The control function is applied to the heat emitter (radiators, underfloor heating, fan-coil unit, indoor unit) at room level; for type 1 one function can control several rooms
1.2	Emission control for TABS (heating mode)	
1.3	Control of distribution network hot water temperature (supply or return)	Similar function can be applied to the control of direct electric heating networks
1.4	Control of distribution pumps in networks	The controlled pumps can be installed at different levels in the network. Control is to reduce the auxiliary energy demand of the pumps
1.5	Intermittent control of emission and/or distribution	One controller can control different rooms/zones having same occupancy patterns
1.6	Heat generator control for combustion and district heating	The goal consists generally in minimizing the heat generator operation temperature
1.7	Heat generator control (heat pump)	The goal consists generally in minimizing the heat generator operation temperature and by this in maximizing the heat generator efficiency
1.8	Heat generator control (outdoor unit)	The goal consists generally in maximizing the heat generator efficiency
1.9	Sequencing of different heat generators	This control function only applies to a system with a set of different heat generator sizes or types including Renewable Energy Sources
1.10	Control of Thermal Energy Storage (TES) charging	The TES is part of the heating system

Each of these services is treated distinctly in the current model so that each specific combination of heat generation, distribution and emission and its associated control can be treated using the EN15232 BACS factor method. The same is true of the other principal TBSs that relate to hot water, cooling, ventilation & AC control, and lighting. Accordingly, the model is structured to allocate the TBS energy use by type of TBS solution installed, and then to overlay the distribution of BACS solutions onto those. The allocation process is based on processing data in the Building Stock Observatory, when available, on type of TBS system (e.g. heating system) and fuel used to derive estimates of the proportion of floor area by building type/location treated by each TBS solution. These are then overlaid by the data on the distribution of BACS class by TBS and location derived in the manner described previously, to obtain a multi-dimensional matrix of: location, building type, TBS type, TBS service and BACS functionality which characterises the European building stock.

Modelling distinct building types

The modelling analysis treats the following building types distinctly in order to capture the primary variations in their usage modes, construction and energy performance characteristics:

- Single family homes (SFH)
- Multi-family residences (MFM)
- Offices
- Retail outlets
- Education establishments
- Hospitality sector buildings
- Healthcare sector buildings
- Other

This segmentation mirrors that reported in the Building Stock Observatory data and hence allows full exploitation of the richness in the available data. It also maps quite closely to the EN15232 BACS factor segmentation which distinguishes BACS factors for the following building types:

- Single family houses
- Apartment block and other residential buildings
- Offices
- Lecture hall
- Education buildings (schools)
- Hospital
- Hotels
- Restaurants
- Wholesale buildings and retail trade service
- Other non-residential building types

Thus, it is possible to directly map the BACS factors to the building types for which there is data in the Building Stock Observatory and hence within the model used for the current analysis.

This segmentation is also important because it allows the EPBD measures which apply preferentially to certain segments of the building stock – most notably the mandatory BACS installation by 2025 for buildings having total effective heating or cooling capacity of > 290 kW - to be treated more realistically.

Determining the proportion of buildings having an effective capacity > 290 kW

As mentioned above, as a key requirement of the revised EPBD is make mandatory the installation of BACS for non-residential buildings having an effective installed heating or cooling capacity of > 290kW it is necessary to determine what proportion of the building stock and building stock energy consumption is expected to be affected by this requirement. There is no data in the building stock observatory or other pan-EU sources on this question, so it is necessary to make use of other sources of information and derive estimates from that.

The approach used in this analysis is to estimate the proportion of total non-residential floor area that is accounted for by buildings that exceed the 290 kW threshold. To do this detailed floor area and installed power data from a major European economy was analysed to establish the proportion of total non-residential floor area that would be subject to this requirement. It was then assumed that the same proportion would apply for the rest of the EU building stock. Interestingly, the finding, that

37% of non-residential building floor area is within buildings having an effective installed heating or cooling capacity of > 290 kW, is quite in line with independent estimates made by eu.bac based on their members project experience and thus would appear to be a reasonable first estimate; however, the actual value for the EU as a whole will probably not be known until Member States begin to report on this requirement.

It is also worth noting that the estimated share of floor area meeting the 290 kW threshold varies by non-residential building type segment with some segments having a higher proportion than others.

Modelling regional and national differences

While there is a certain degree of commonality among some building types across geographical variations there are also some systematic differences. Key differences are those due to variations in climate, culture – which can affect usage profiles and construction styles, economic factors and energy prices. There are also differences in wages and the degree of professional qualifications hat can affect labour costs associated with BACS installations.

In the current analysis the national level data reported in datasets, such as the Building Stock Observatory, are respected at the source level but are then aggregated into 3 broad climatic regions to represent the EU as a whole, see Figure 1: EU-West (in green), EU North (comprising Scandinavia and EU-North East region in purple) and EU South (comprising the yellow and red shaded countries). This is consistent with the regional treatment applied in the recast EPBD impact assessment.

Figure 1. EU regions treated in the anal

Primary energy factors

The primary energy factors used in the report are aligned with those reported in the *Agreed Amendments* scenario from the recast EPBD impact assessment. As they assume that the electricity sector decarbonises over the scenario period in line with other EU policy objectives they decrease progressively with time so that electricity consumption can have a lower primary energy factor than thermal energy sources late in the scenario period.

CO_2 emissions factors

The CO_2 emissions factors are also aligned with those from the *Agreed Amendments* scenario from the recast EPBD impact assessment. As mentioned above the electricity emission factors and also district heating emission factors decline over time due to the decarbonisation of the fuels they use.

Energy prices

As with other input variables energy prices for all the scenarios are aligned with those assumed in the *Agreed Amendments* scenario from the recast EPBD impact assessment. It should be mentioned that these appear to be quite conservative relative to other EU long range energy and emissions scenarios.

3.2 BACS costs

BACS costs are treated in the model on a per unit area basis by type of building, TBS and BACS energy performance class. For simplicity the values used in the study are aligned with those reported in other studies (e.g. WSE (2014), Ecofys and WSE (2017), and VITO *et al* (2018)); however, these may well overestimate the true costs associated with a significant increase in BACS deployment because they assume no economies of scale whereas in reality a significant proportion of BACS costs are related to labour including marketing and sales support, both of which may well scale down on a per unit deployment basis if BACS deployment is significantly accelerated. The same is true of the incremental cost of Class A solutions compared to Class B, C or D, because while Class A solutions are always expected to be more labour intensive and have higher material costs these should scale downwards on a per unit basis as they become more common place.

One refinement included in the current analysis is to estimate how the actual cost of BACS would be expected to vary by region. This was done through attributing BACS costs to hardware and labour related costs and then assessing how the later would be expected to vary by country and region given the available statistics on differences in Labour costs. The hardware costs are assumed to be constant across the EU. This leads to per unit area installed BACS costs in the EU North region which are ~27% below those in the West Region, while those in the South region are ~23% lower. Another key aspect in treating costs is to consider the distinction in investment costs between those cases where the recast EPBD BACS-related policy measure simply ensures that a BACS that was going to be installed is a comparatively efficient system, and those where the policy measure requires a BACS system to be installed when no BACS would have been installed in the absence of the measure. In the former case the BACS cost attributable to the policy measure is simply the incremental cost between the default system that would have been installed with no policy measures and the efficient one that is installed due to the policy measures. In the latter case, the full BACS system cost needs to be accounted for. The latter case applies in the case for the mandatory installation of BACS in buildings having >290kW of effective installed capacity, but otherwise it is predominantly the former case.

3.3 The BACS scenarios considered

To determine the impact of the BACS measures within the recast RPBD the following two scenarios are modelled for this analysis:

- the ***EPBD compliant*** scenario (which is compliant with the recast EPBD including with regard to its BACS-related policy measures)
- the ***EPBD compliant without BACS*** scenario (which is the same as the above except that the BACS-related policy measures are not implemented)

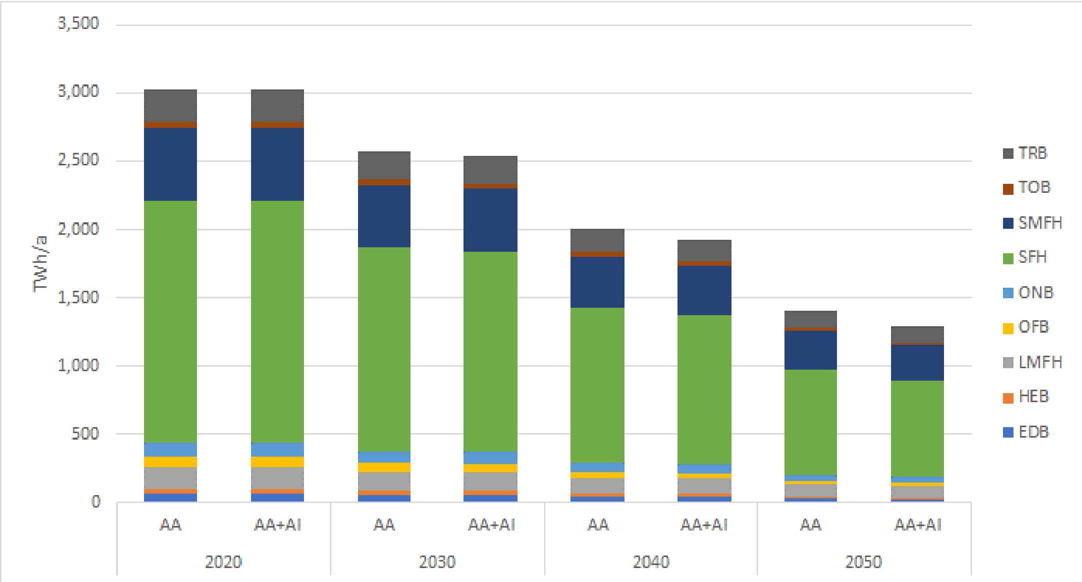
The difference in impacts between these two scenarios is the estimated impact of the BACS measures within the recast EPBD.

The first of these scenarios complies with all the provisions of the EPBD and this can be considered to be EPBD compliant. This means that it is directly equivalent to the "*Agreed Amendments*" pathway reported in the EPBD Impact Assessment (Ecofys 2016). Thus, the above *EPBD recast including the impact of BACs measures* scenario is identical to the *Agreed Amendments* pathway and has the parameters and assumptions for the building sector pathways which were defined in the report and modelling work by Ecofys for the EC study *"Ex-ante evaluation and assessment of policy options for the EPBD"*. The details of this scenario, including its energy impacts, are now described.

The EPBD compliant = "agreed amendments" scenario

ECOFYS (2016) and VITO *et al* (2018) show the evolution of final energy consumption for space heating in the EU to 2050 under the *Agreed Amendments* scenario. In 2020 the final energy consumption for space heating is 3050 TWh/year but by 2050 this has fallen by 53% to 1400 TWh/year. Also shown in this figure is the "Agreed Amendments + Ambitious implementation" scenario, where the final energy consumption for space heating falls by about 58% in 2050 compared to 2020. This is one of the scenarios reported in the impact assessment that estimate what would happen were Member States to take an ambitious approach to implementing the recast EPBD rather than simply fulfilling the minimum requirements. In both cases the main drivers behind the energy savings are energy efficiency measures applied to the building envelopes and the replacement of old heating, hot water and cooling systems across EU. At the same time the floor area is steadily increasing due to the construction of new buildings and additions to existing buildings that are not being fully offset by demolition. The total floor area is therefore estimated to increase by approximately 15% from 2020 until 2050.

Figure 2. EU total final heating energy consumption per type of heating system[6] under the Agreed Amendments scenario (Ecofys 2016)



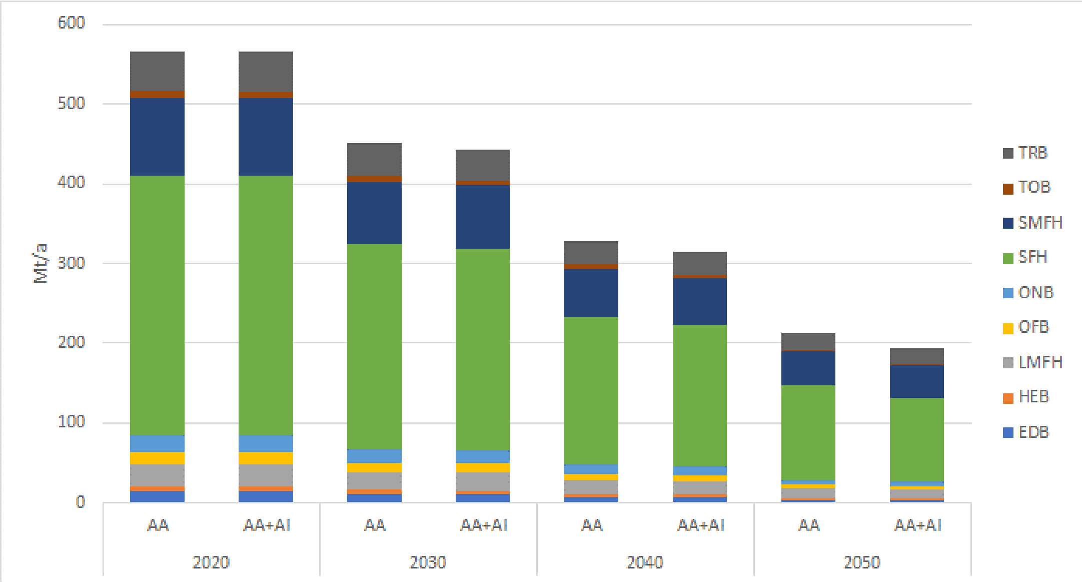
Key	SFH	Single Family Housing	TOB	Touristic
	SMFH	Small Multi-family Housing	HEB	Health
	LMFH	Large Multi-family Housing	ONB	Other
	OFB	Office	AA	Agreed amendments scenario
	TRB	Trade	AA+AI	Agreed amendments with ambitious implementation scenario
	EDB	Education		

In primary energy terms, the energy savings are even more pronounced since fuel switching in the case of heating system replacement not only leads to efficiency improvements, but also to a further decrease in the consumption of primary energy. Where heat pumps are introduced, the higher efficiency of heat pumps leads to lower overall primary energy demand. In addition, the primary energy factor (PEF) for electricity and district heating is expected to improve (i.e. decline) over time due to the increased use of renewable energy sources.

Similar factors result in the CO_2-emissions for heating in the "Agreed Amendments" scenario decreasing by 61% in 2050 compared to 2020, as CO_2 emissions factors are improving over time and a switch to less carbon-intensive energy carriers further supports the decarbonisation effect, see ECOFYS (2016) and also VITO *et al* (2018)**Error! Reference source not found.**.

[6] Abbreviations in the figures: VS: Ventilation system, HR: Heat recovery, c: condensing system, nc, non-condensing system, HP: Heat pump, DH: District heat, EL: Electricity.

Figure 3. Total EU CO_2 emissions from heating per reference building[7]



ECOFYS (2016) & VITO *et al* (2018) summarize the estimated total electricity consumption under the *Agreed Amendments* scenario for the years 2023, 2030, 2040 and 2050. As gas-condensing boilers are the main heating systems deployed in the "Agreed Amendments" building sector pathway, the electricity consumption for heating decreases over time. This trend is compounded due to the phase out of resistance electric space heating in favour of more efficient heat pump solutions. The electricity consumed by sanitary hot water is stable (due to the increasing efficiencies of heating systems on the one hand being offset by increasing building stock floor area on the other). In contrast, cooling and auxiliary electricity consumption is projected to increase over time due to the increase in demand for the related services more than offsetting the projected improvements in efficiency. In the case of lighting, the increase in efficiency of lighting technologies is a greater effect than the increase in demand for lighting and thus the electricity demand from lighting decreases slightly over time despite considerable projected growth in lighting demand.

Table 2. Electricity consumption in EU buildings under the "Agreed Amendments" scenario[8]

BACS shares	2020	2030	2040	2050
Heating	233	191	140	88
Hot water	47	47	46	44
Cooling	38	43	45	47
Auxiliary electricity	76	92	96	101
Lighting	258	201	211	221
Sum	651	574	539	501

[7] Abbreviations in the figures: Office Building (OFB), Trade and Retail Building (TRB), Education Building (EDB),
Touristic Buildings (TOB), Health Buildings (HEB), Other non-residential buildings (ONB).
[8] Abbreviations: Aux. el = auxiliary electricity (i.e. pumps, fans etc.), n-res = non-residential buildings

The EPBD compliant without BACS scenario

For this scenario its necessary to estimate how the use and efficiency of BACS in the EU building stock would be expected to evolve without the additional stimulus of the BACS-related measures set out in the recast EPBD. It could be argued that the original EPBD includes some indirect encouragement to BACS because it recognises building energy performance through EPCs and it sets whole building energy performance requirements for new construction and major renovations. In practice, though, these measures are only likely to provide a very limited stimulus to the use of BACS. While some EPCs were based on energy bills, which would reflect the impact of BACS in practice, most are based on calculated performance. For those using calculated performance only very few Member States have encoded BACS, even partially, into their calculation methodologies and it is thought that only one or two have coded EN15232 into the performance calculation software. Even in the cases where EPCs are based on measured bills rather than calculations, there is no explanation of the performance attained and hence no means of making the BACS contributions visible and hence tangible. Without this transparency market actors are often likely to be unaware of the contribution that BACS can make to the energy performance of their buildings and hence the potential stimulus effect to the adoption of cost-optimised BACS solutions is heavily diluted. In the case of new construction or major renovations there is another barrier. Project developers will usually want certainty that the project will meet prescribed energy performance limits. BACS are one of the last elements with an impact on a building's energy performance to be installed and so rather than risk that something goes awry at that stage many project developers and managers are likely to "front-end" the energy performance decisions so that the building is expected to be compliant without waiting for the BACS contribution to the overall energy balance. In part, this is due to developers and project managers wishing to control contractors they have the most sustained interaction with and most influence over, and these are not traditionally the building services engineers who are responsible for the automation and control systems and who tend to be brought in at the end of a construction project.

Nonetheless, the BACS market exists and continues to develop. Estimates in various studies including (Ecofys and WSE 2017[9], WSE 2014, VITO et al 2018) have tended to coalesce around a BACS deployment rate under a business as usual scenario (i.e. non recast EPBD) of about 1.2% per year.

Based on a recent study by Ecofys and Waide Strategic Efficiency (2017) this baseline scenario assumes a yearly deployment rate of SRTs of 1.2%. This is also consistent with the assumptions reported on BACS deployment in the recent Smart Readiness Indicator study for DG Energy (VITO *et* al, 2018).

Mapping the EPBD BACS measures to BACS installation and replacement events

In an ordinary progression BACS may be installed whenever:

a) there is a new construction event (e.g. a new build or major renovation project)

b) a technical building system is renewed or replaced, or

c) as an add-on or improvement to existing control systems

In general, some form of BACS will almost always be installed for case a) so such events are effectively a trigger point for new BACS in ~100% of cases. Case b) will often result in renewal of BACS, at least the part of the BACS which control the TBS in question, but there can also often be cases where a TBS is replaced yet the existing BACS are left in situ. Case c) is the rarest case for BACS renewal as it is not triggered by another event and thus building owners would need to be sufficiently motivated by, and aware of, the potential benefits of enhanced BACS functionality to procure BACS in isolation of any other drivers.

[9] Ecofys & WSE (2017), Optimising the energy use of technical building systems: Unleashing the power of the EPBD's Article 8 – Ecofys and Waide Strategic Efficiency for Danfoss

These cases set out the events that will drive BACS installations under a business as usual scenario.

The EPBD recast policy measures add to this in the following ways. Firstly, they require BACS to be installed in all non-residential buildings having an effective rated heating or cooling capacity above 290kW by 2025. If this provision is respected it would result in all such buildings having BACS installed by 2025.

To model the effect of these measures it will be necessary to establish:

- the part of the building stock that is affected by the measure (differentiated by building type, floor area and energy consumption profiles)
- the baseline for BACS adoption in that part
- the extent to which the measure increases BACS adoption
- the extent to which the measure increases the functionality and energy savings potential of the BACS installed.

Furthermore, while the implementation of some of the EPBD recast measures are quite unambiguous others are sensitive to how Member States decide to interpret and implement the requirements, thus interpretation and judgement is needed to estimate this.

Eu.bac have developed a set of guidelines[10] on the implementation of the EPBD policy measures related to BACS which set out their interpretation of the requirements and by and large the assumptions in this study are in line with these. Overall this tends towards class B BACS being installed as the minimum compliant response to the EPBD provisions whenever they trigger a BACS installation event; however, it varies depending on context. For example, in each of the three scenarios if an existing BACS is renewed it is never replaced by BACS having in inferior energy performance class, thus it is assumed there is never any backsliding. Equally, while there is no back sliding there are varying probabilities ascribed to the likelihood that a renewed BACS installation will jump up one or more classes (depending on the start point). The scenarios are structured to take account of both the expected frequency of trigger events and the strength of stimulus to increase one or more energy performance classes – these vary as a function of: the specific BACS policy measure(s) which applies(y) to the TBS and building type, and the starting point of the existing BACS class.

The most dramatic stimulus to trigger BACS deployment is the requirement that non-residential buildings having >290 kW of effective installed capacity for heating or cooling should have BACS installed by 2025. This means that if complied with, all such buildings would have BACS by that time and thereby require review and installation actions which are quite apart from standard building element replacement cycles. The Article 14 and 15 policy measures tied to the heating and cooling system inspection process will follow that inspection cycle, and hence are dependent on how these are implemented in each Member State. By contrast the Article 8 measures regarding the imposition of minimum energy performance requirements for technical building systems are related to the nature of requirements set by Member States and the new or replacement installation rates. Examples of how this affects the change in the stock of BACS by efficiency class are given in Tables 3 and 4.

[10] *Summary of Guidelines for the transposition of the new EPBD in Member States*, eu.bac

Table 3. Projected evolution in space heating BACS energy performance class shares for space heating in single family homes in the Western region under the EPBD compliant with no BACS scenario

BACS class	2020	2025	2030	2035	2040	2045	2050
A	0.5%	2.0%	3.5%	5.2%	7.0%	8.9%	10.9%
B	6.5%	9.8%	12.8%	15.4%	17.7%	19.7%	21.4%
C	78.4%	74.5%	70.7%	67.2%	63.8%	60.6%	57.5%
D	9.8%	9.2%	8.7%	8.1%	7.7%	7.2%	6.8%
No BACS	4.9%	4.6%	4.3%	4.1%	3.8%	3.6%	3.4%

Table 4. Projected evolution in space heating BACS energy performance class shares for space heating in single family homes in the Western region under the EPBD compliant scenario

BACS class	2020	2025	2030	2035	2040	2045	2050
A	1.9%	6.5%	11.2%	15.8%	20.2%	24.5%	28.6%
B	12.2%	26.7%	36.9%	43.9%	48.5%	51.2%	52.5%
C	72.4%	56.4%	44.0%	34.2%	26.7%	20.8%	16.2%
D	9.0%	6.9%	5.3%	4.0%	3.1%	2.4%	1.8%
No BACS	4.5%	3.4%	2.6%	2.0%	1.5%	1.2%	0.9%

While the policy measures applying to residential buildings within the recast EPBD lead to a smooth acceleration in the deployment of BACS, in the non-residential sector the increase is much sharper in the years up to 2025 due to the requirement for buildings with >290 kW in installed capacity to have BACS in place by 2025.

Each annual set of BACS class shares is then converted into an installed stock-weighted average BACS factor where the lower the number the more efficient the technical building system control and the lower its energy consumption. These stock-weighted average BACS factors are reported for each TBS, building type and scenario in Appendix C for each of the three grouped regions.

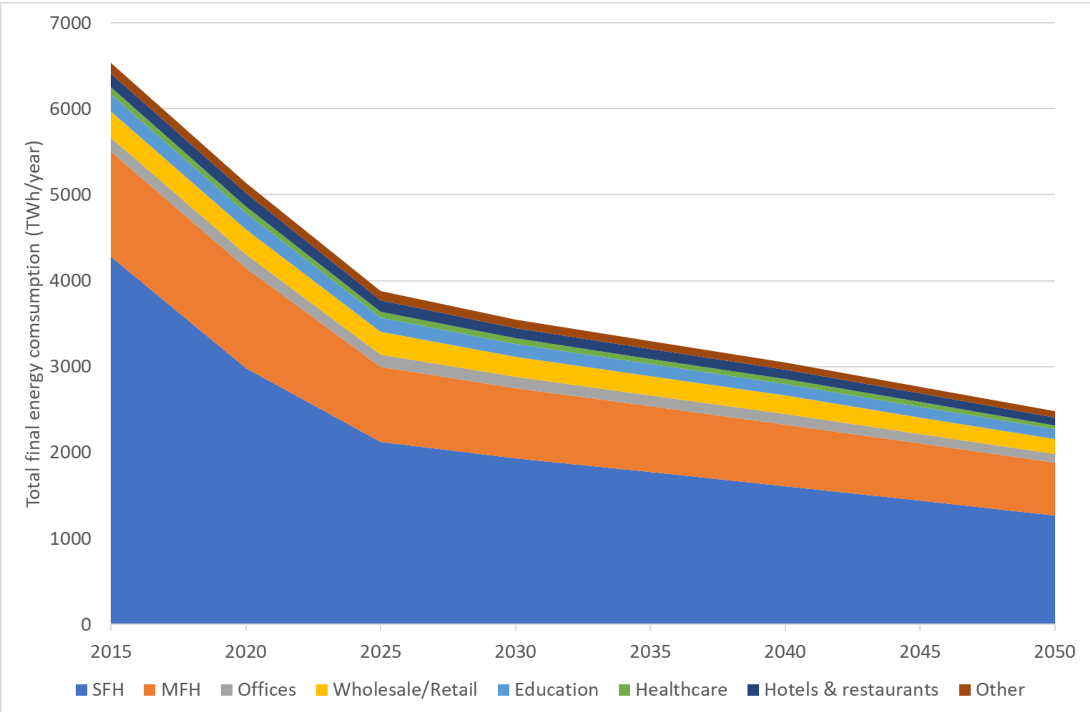
4. Results: the impact of the EPBD BACS measures on overall savings

The aim of the study is to model the impact of the revised EPBD provisions for BACS to determine the impact that the BACS measures within the EPBD would be expected to deliver assuming that they are fully respected. This is important because while the EPBD was the subject of a general impact assessment it ran ahead of, but also partially in parallel, with the development of the revised text and did not explicitly separate out the effects of the measures pertaining to BACS but rather integrated them into the overall findings.

4.1 EU level results

As mentioned previously the impact assessment of the recast EPBD foresees a substantial fall in the total energy consumption of European buildings under the Agreed amendments scenario. As this is the same as the EPBD compliant scenario the trends in energy consumption by building type across the EU are as shown in Figure 4.

Figure 4. Total final energy consumption by building type under the *EPBD compliant* scenario



Under the three BACS related scenarios modelled in the current analysis the overall total final energy consumption of the EU building stock is projected to vary as shown in Figure 5. The blue line is the *EPBD compliant* scenario whereas those above it are the *EPBD compliant without BACS* and the *Frozen BACS* scenarios. The corresponding data is also reported in Table 5.

Figure 5. Total final energy consumption for EU buildings by scenario

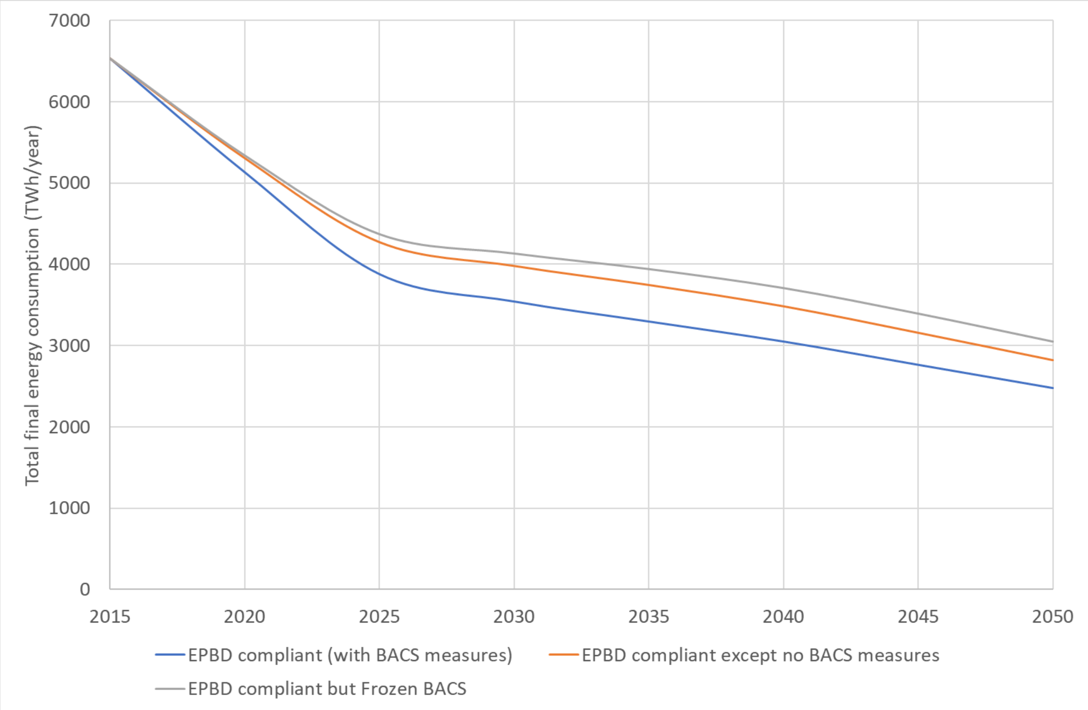


Table 5. Projected evolution in total final energy consumption (TWh) for the EU building stock per scenario

Scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant	5135	3880	3544	3297	3050	2764	2478
EPBD compliant without BACS	5308	4273	3981	3746	3483	3157	2819
EPBD compliant but Frozen BACS	5343	4376	4138	3946	3712	3398	3054

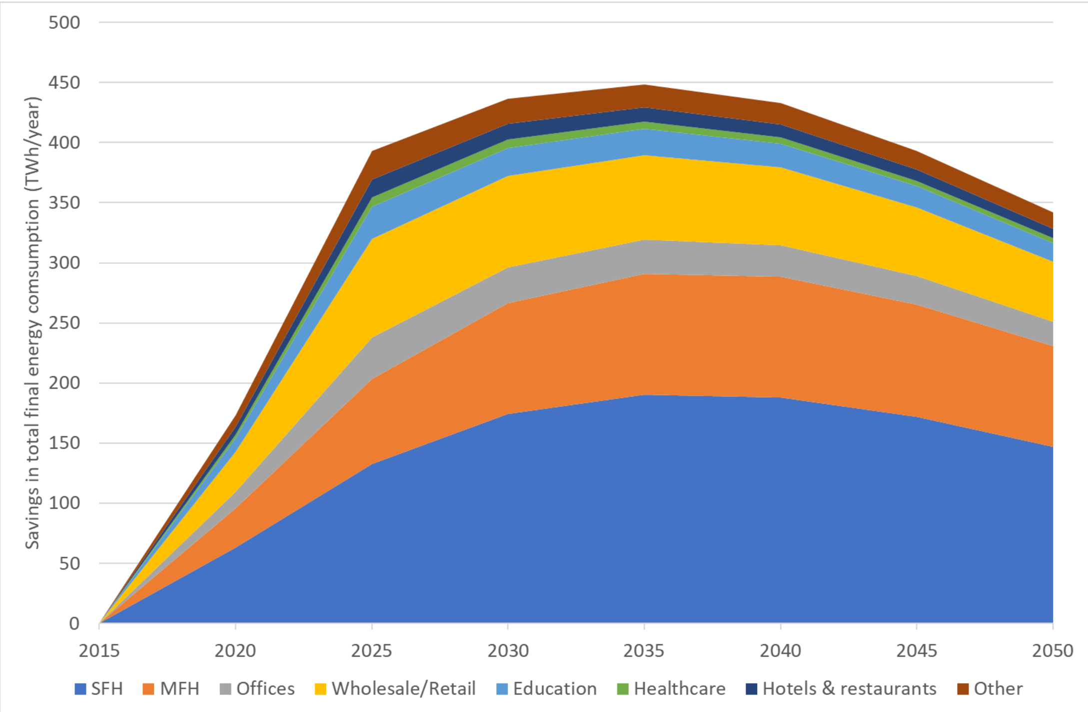
This translates into the total final energy savings due to the BACS policy measures in the recast EPBD as compared to the BACS business as usual case corresponding to the *EPBD compliant without BACS* scenario shown in Table 6 and Figure 6.

The total savings due to the BACS measures in the recast EPBD are projected to peak at 450 TWh of final energy in 2035. Thereafter the additional savings diminish as the BACS deployment in the business as usual (*EPBD compliant without BACS* case) begins to attain a similar rate while the total building energy consumption continue to decline.

Table 6. Projected savings in total final energy consumption (TWh) for the EU building stock for the *EPBD compliant* scenario compared with the other scenarios

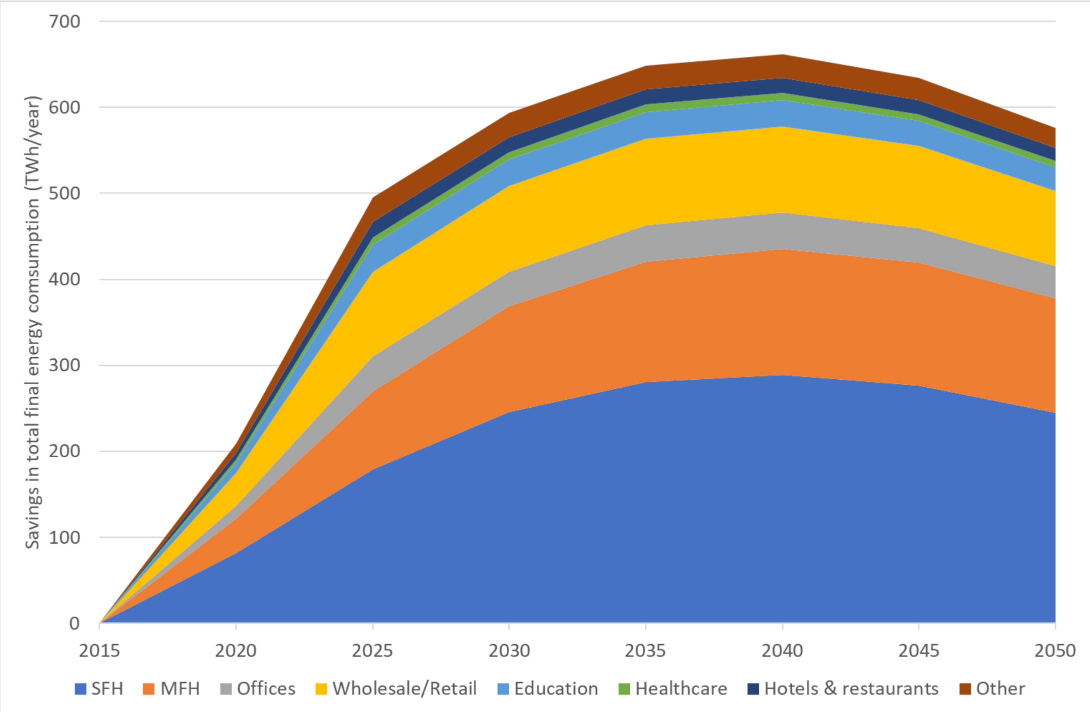
Savings compared to scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant without BACS	173	393	437	449	433	393	342
EPBD compliant but Frozen BACS	209	496	594	649	662	635	576

Figure 6. Savings in total final energy consumption of EU buildings for the *EPBD compliant* compared to the *EPBD compliant without BACS* scenario



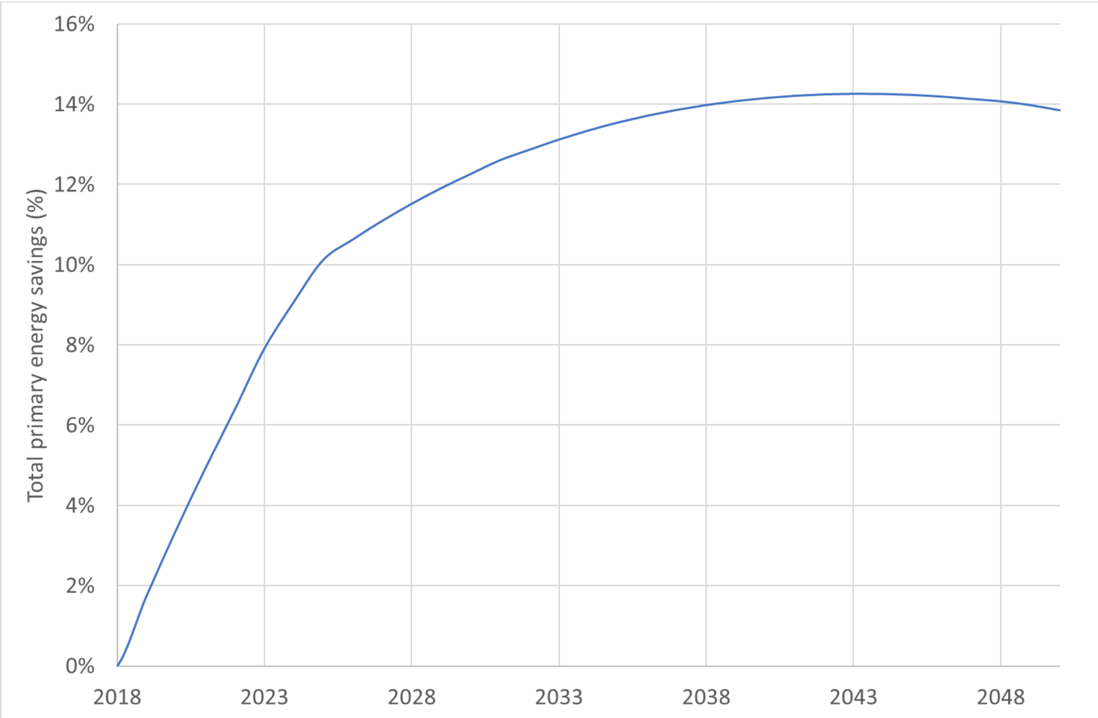
The equivalent savings in total final energy consumption under the EPBD compliant scenario compared with a static BACS case (i.e. the Frozen BACS scenario) are shown in Figure 7. In this case the total final energy savings peak in 2040 at about 660 TWh/year.

Figure 7. Savings in total final energy consumption of EU buildings for the *EPBD compliant* compared to the *Frozen BACS* scenario



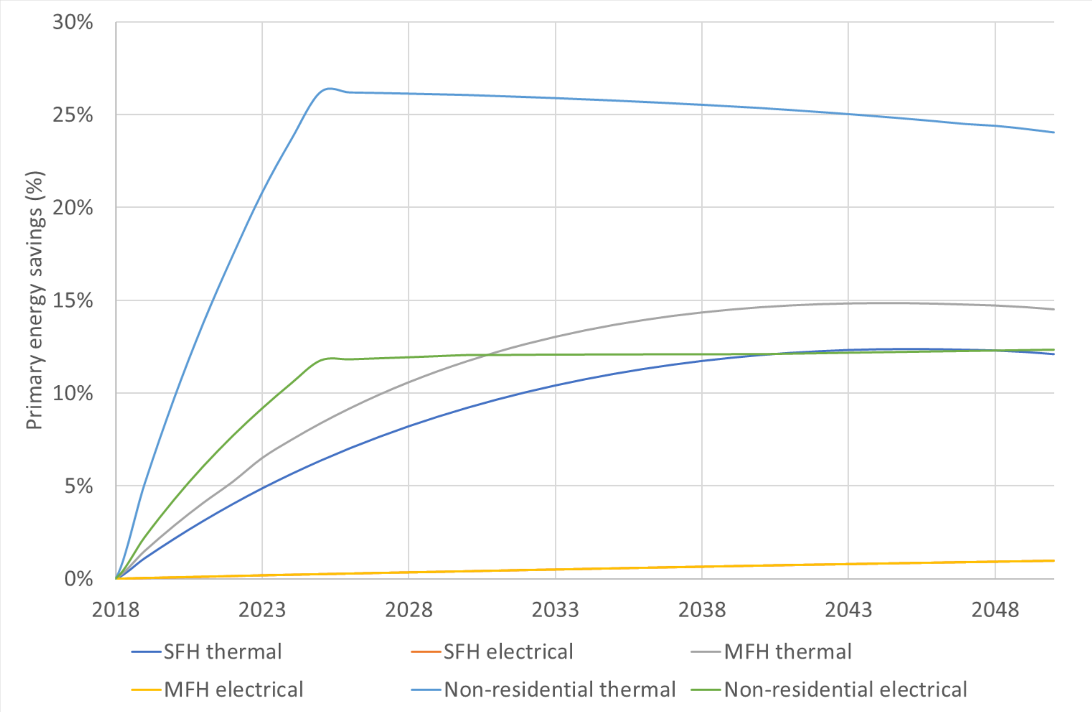
The percentage savings in total primary energy consumption of EU buildings under the *EPBD compliant* scenario compared to the *EPBD compliant without BACS* scenario are shown in Figure 8. The percentage savings peak at about 14.2% in 2043. The difference in the peak (2043 compared with 2035) compared with Figure 6 is explained by the decline in total building energy consumption due to the ensemble of EPBD recast policy measures. It is important to appreciate that these percentage energy savings would be expected to be stable regardless of the pace of improvement in the energy performance of non-BACs related aspects of the building stock. Thus, were the improvement in stock energy consumption not to be as rapid as projected in the Agreed Amendments scenario but the recast EPBD BACS measures to be implemented then the absolute level of energy savings would increase compared with the values shown in Figure 6.

Figure 8. Total primary energy savings for all buildings for the *EPBD compliant* scenario compared to the *EPBD compliant without BACS* scenario



It is pertinent to see how the primary energy savings would be expected to vary by building type. Figure 9 shows this for the EU building stock by the main types of residential buildings and with non-residential buildings grouped together (as the BACS-related policy measures target them in an equivalent way). This illustrates that, due to the requirement for non-residential buildings with >290 kW of effective installed heating or cooling capacity to have BACS installed by 2025, the pace of energy saving rises sharply to 2025, peaking at 27% for thermal energy sources, and then declines gently thereafter (as the gap in BACS deployment under the *EPBD compliant without BACS* (Business as usual case) and the policy case (*EPBD compliant*) erodes. The savings are significantly higher for thermal than electrical end-uses, which is important from a policy perspective as the thermal end-uses are likely to remain carbon intensive for longer than the electrical end-uses. Nonetheless the electrical savings in the non-residential sector are still quite appreciable at about 12%. In the residential sector the pace of savings rises more gradually as the policy measures mostly apply at trigger points that are in-step with natural installation cycles for technical building systems. In this case the thermal energy savings peak at about 15% for multi-family housing and 12.5% for single family housing, both in 2043. Electrical primary energy savings in both single and multi-family housing are much more modest rising to about 1.5% by the end of the scenario period. The large difference in the electrical energy savings in the non-residential compared to residential cases is explained by the much greater proportion of electricity consumption in non-residential buildings associated with technical building systems (e.g. ventilation, air conditioning, lighting) where there are significant BACS-related savings potentials than in residential buildings where plug loads dominate.

Figure 9. Total primary energy savings by principal building and fuel type for the *EPBD compliant* scenario compared to the *EPBD compliant without BACS* scenario



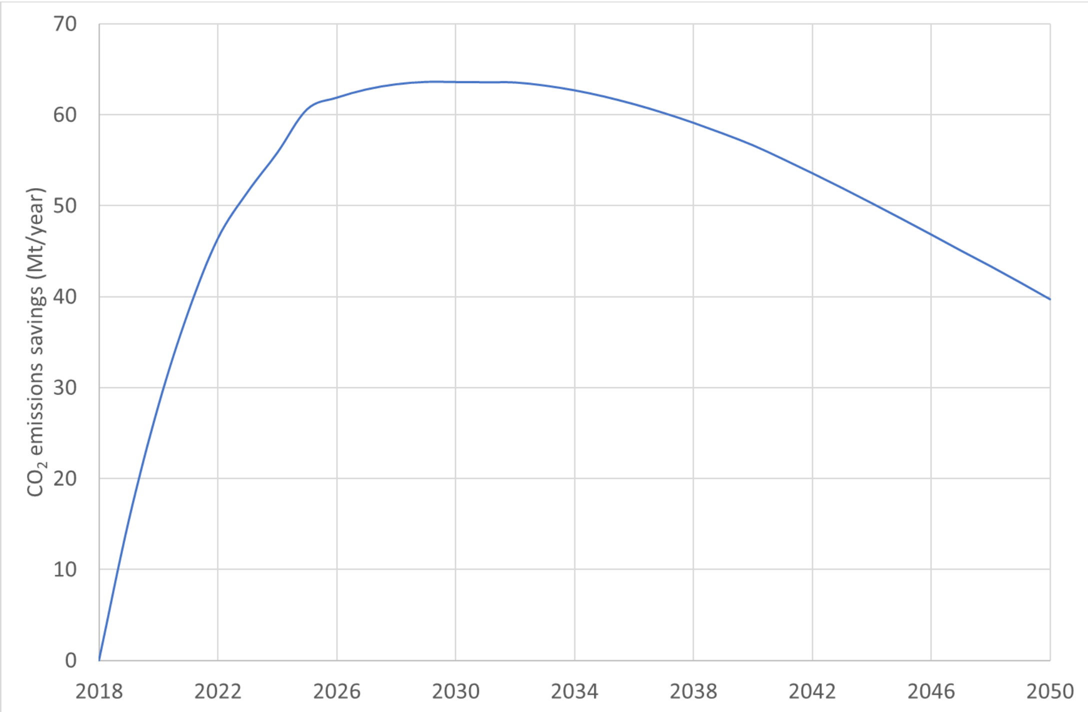
Environmental impacts

The energy savings due to the extra BACS measures implemented through the EPBD lead to the CO_2 emissions savings shown in Figure 10 and Table 7. Emissions savings peak at 63.8 Mt in 2031 and then decline thereafter. The rate of decline is greater than the corresponding rate in decline in energy savings due to the progressive decarbonisation of the energy system projected under the *EPBD compliant* (= Agreed Amendments) scenario, in line with EU energy sector policy (see Figure 3). Over the entire scenario period it is projected that some 1698 Mt of CO_2 emissions are projected to be avoided due to the BACS-related measures in the recast EPBD.

Table 7. Projected savings in CO_2 emissions (million tonnes) for the EU building stock for the *EPBD compliant* scenario compared with the other scenarios

Savings compared to scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant without BACS	28.0	60.6	63.6	62.0	56.7	48.6	39.7
EPBD compliant but Frozen BACS	33.8	76.4	86.5	89.7	86.7	78.4	67.0

Figure 10. Total avoided CO_2 emissions for the *EPBD compliant* scenario compared to the *EPBD compliant without BACS* scenario



Economic impacts

The estimated level of investments necessary to achieve these energy savings are shown in Figure 11 and Table 8. They rise relatively steeply to a peak of €7.4 billion in 2022 due to the stimulus of the mandatory BACS requirement in a proportion of the non-residential building stock. In 2026 they have a sharp drop to €4.3 billion as the mandatory installation in non-residential buildings with an equivalent total installed capacity > 290kW is completed. They then steadily decline to €570 million in 2047 by which time the BACS in all building which were existing at the beginning of the scenario period have been replaced at least once. Thereafter, the incremental investment is relatively constant in line with the rate of new build.

Figure 11. Additional investments in BACS for the *EPBD compliant* scenario compared to the *EPBD compliant without BACS* scenario

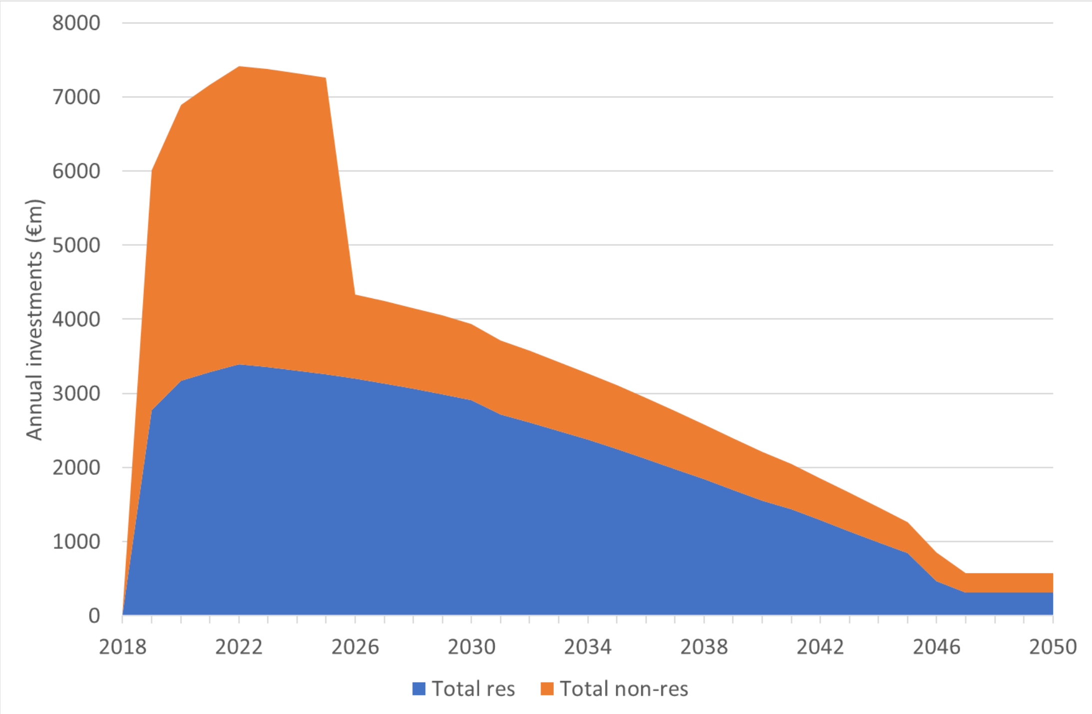


Table 8. Projected evolution in incremental BACS investments (€ million) for the EU building stock for the *EPBD compliant* compared with the *EPBD compliant without BACS* scenario

Building type	2020	2025	2030	2035	2040	2045	2050
Residential	3175	3255	2905	2248	1557	841	313
Non-residential	3719	4002	1032	862	652	423	261
All buildings	6893	7257	3937	3110	2209	1264	574

The estimated value of the avoided energy bills due to these investments is shown in Figures 12 and 13, and Table 9. These rise sharply to about €32 billion in 2025 then rise more gradually to a peak of €36 billion in 2035 before gently declining thereafter. The value of the energy savings far exceeds the cost of the investments. Over the whole scenario period the value of energy savings exceeds the value of investments by a factor of 9 (of which it is a factor of 8.1 for residential buildings and 10.4 for non-residential buildings). While these factors show the BACS measures in the EPBD are very cost effective they are less than reported in previous studies such as WSE (2014) and Ecofys & WSE (2017) principally because the *EPBD compliant* (= "Agreed Amendments") scenario assumes a very sharp decline in EU building stock energy consumption due to the ensemble of recast EPBD measures, whereas in the other analyses the building stock exhibits a much more gradual change in energy consumption for non-BACS related changes. Were, for any reason, the building stock energy use not to decline as rapidly as projected under the *EPBD compliant* scenario then the ratio of bill savings to investment costs would increase above the values reported above.

Figure 12. Avoided (saved) energy bill costs for the *EPBD compliant* scenario compared to the *EPBD compliant without BACS measures* scenarios

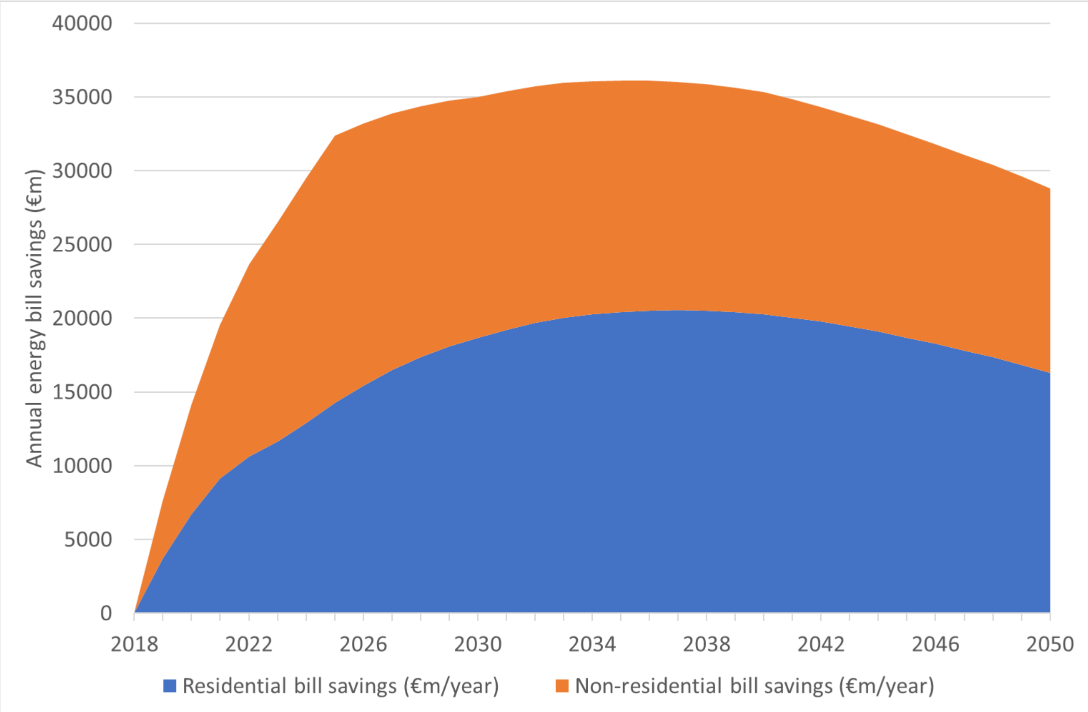
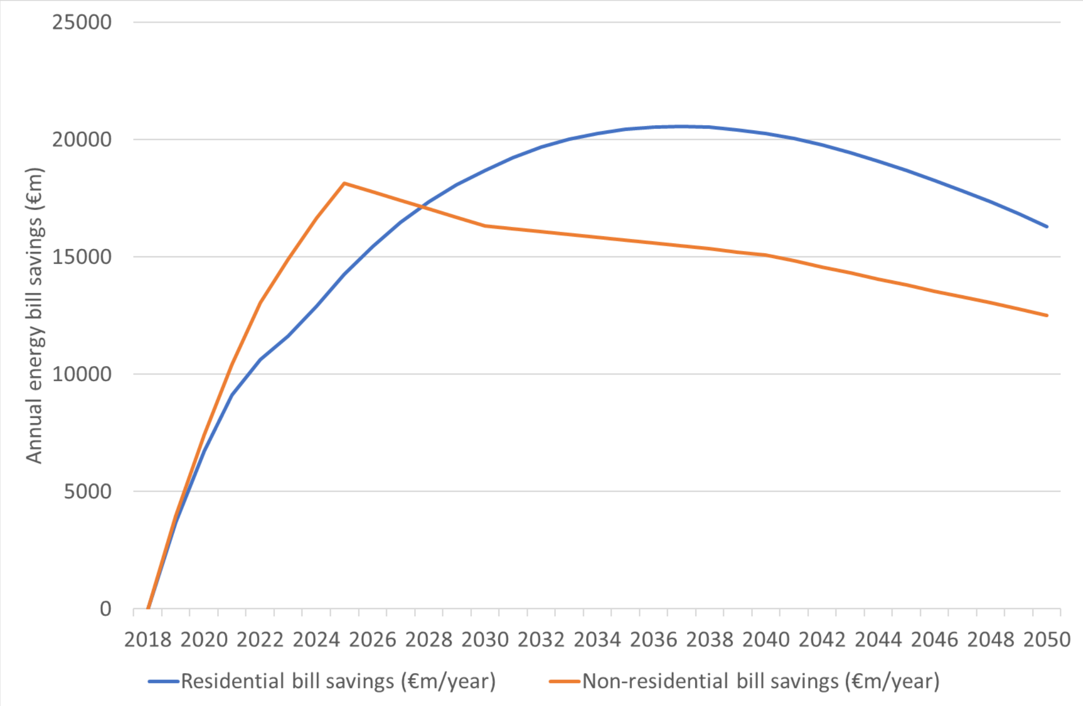


Table 9. Projected evolution in annual energy bill savings (€ million) for the EU building stock for the *EPBD compliant* compared with the *EPBD compliant without BACS* scenario

Building type	2020	2025	2030	2035	2040	2045	2050
Residential	6704	14254	18677	20433	20263	18687	16288
Non-residential	7402	18130	16301	15701	15083	13796	12509
All buildings	14105	32385	34978	36134	35346	32483	28797

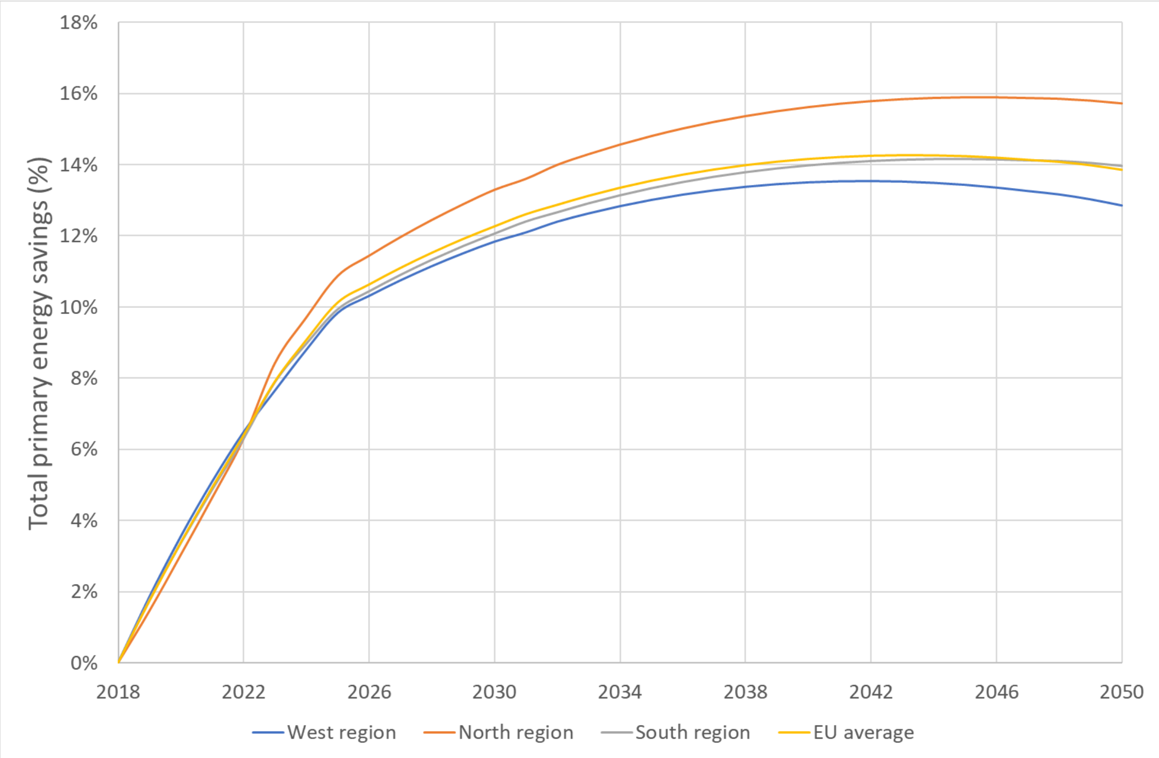
Figure 13. Avoided (saved) energy bill costs for the *EPBD compliant* scenario compared to the *EPBD compliant without BACS measures* scenarios



4.2 Regional results

Underpinning the results presented for the EU as a whole are the regional level impacts. The relative savings in primary energy for the building stock per major region (see section 4.1 for the explanation of these groupings) are shown in Figure 14. Overall the highest percentage savings occur in the EU north region (comprising north eastern EU and Scandinavia) and the lowest in the large EU West region; however, as the consumption of the EU west building stock is considerably higher than in the other regions (due to having a much greater proportion of the EU's building stock floor area) the EU average is closer to this (the EU average is also close to the EU south region).

Figure 14. Total primary energy savings for all buildings for the *EPBD compliant* scenario compared to the *EPBD compliant without BACS* scenario by region



Results for EU North region

The corresponding impacts and savings in the EU north region are shown in Tables 10 to 14.

Table 10. Projected evolution in total final energy consumption (TWh) for the EU North region building stock per scenario

Scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant	1051	666	615	577	538	494	449
EPBD compliant without BACS	1084	741	700	666	626	576	523
EPBD compliant but Frozen BACS	1092	760	730	705	672	625	573

Table 11. Projected savings in total final energy consumption (TWh) for the EU North region building stock for the *EPBD compliant* scenario compared with the other scenarios

Savings compared to scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant without BACS	33	75	85	89	88	82	74
EPBD compliant but Frozen BACS	41	94	115	128	133	131	124

Table 12. Projected savings in CO_2 emissions (million tonnes) for the EU North region building stock for the *EPBD compliant* scenario compared with the *EPBD compliant without BACS* scenario

Savings compared to scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant without BACS	5	12	12	12	11	10	9

Table 13. Projected evolution in incremental BACS investments (€ million) for the EU North region building stock for the *EPBD compliant* compared with the *EPBD compliant without BACS* scenario

Building type	2020	2025	2030	2035	2040	2045	2050
Residential	472	457	418	324	229	144	69
Non-residential	505	513	146	127	102	74	53
All buildings	977	970	564	451	332	218	122

Table 14. Projected evolution in annual energy bill savings (€ million) for the EU North region building stock for the *EPBD compliant* compared with the *EPBD compliant without BACS* scenario

Building type	2020	2025	2030	2035	2040	2045	2050
All buildings	2729	6192	6830	7171	7161	6771	6231

Results for EU South region

The corresponding impacts and savings in the EU north region are shown in Tables 15 to 19.

Table 15. Projected evolution in total final energy consumption (TWh) for the EU South region building stock per scenario

Scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant	1574	852	811	783	755	720	684
EPBD compliant without BACS	1623	930	902	882	856	817	776
EPBD compliant but Frozen BACS	1633	949	934	924	907	874	836

Table 16. Projected savings in total final energy consumption (TWh) for the EU South region building stock for the *EPBD compliant* scenario compared with the other scenarios

Savings compared to scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant without BACS	48	77	91	99	101	98	92
EPBD compliant but Frozen BACS	58	97	123	141	151	154	151

Table 17. Projected savings in CO_2 emissions (million tonnes) for the EU South region building stock for the *EPBD compliant* scenario compared with the *EPBD compliant without BACS* scenario

Savings compared to scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant without BACS	5	12	12	12	11	10	9

Table 18. Projected evolution in incremental BACS investments (€ million) for the EU South region building stock for the *EPBD compliant* compared with the *EPBD compliant without BACS* scenario

Building type	2020	2025	2030	2035	2040	2045	2050
Residential	970	903	796	610	415	210	66
Non-residential	740	730	171	141	105	66	38
All buildings	1710	1633	966	751	520	276	104

Table 19. Projected evolution in annual energy bill savings (€ million) for the EU South region building stock for the *EPBD compliant* compared with the *EPBD compliant without BACS* scenario

Building type	2020	2025	2030	2035	2040	2045	2050
All buildings	3937	6363	7326	7968	8220	8059	7740

Results for EU West region

The corresponding impacts and savings in the EU north region are shown in Tables 20 to 24.

Table 20. Projected evolution in total final energy consumption (TWh) for the EU West region building stock per scenario

Scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant	2509	2362	2118	1937	1756	1550	1344
EPBD compliant without BACS	2601	2603	2378	2198	2001	1764	1520
EPBD compliant but Frozen BACS	2619	2666	2473	2317	2134	1899	1645

Table 21. Projected savings in total final energy consumption (TWh) for the EU West region building stock for the *EPBD compliant* scenario compared with the other scenarios

Savings compared to scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant without BACS	91	241	260	261	245	214	176
EPBD compliant but Frozen BACS	110	304	355	380	378	349	301

Table 22. Projected savings in CO_2 emissions (million tonnes) for the EU West region building stock for the *EPBD compliant* scenario compared with the *EPBD compliant without BACS* scenario

Savings compared to scenario	2020	2025	2030	2035	2040	2045	2050
EPBD compliant without BACS	15	37	38	36	32	26	20

Table 23. Projected evolution in incremental BACS investments (€ million) for the EU West region building stock for the *EPBD compliant* compared with the *EPBD compliant without BACS* scenario

Building type	2020	2025	2030	2035	2040	2045	2050
Residential	2008	1895	1691	1313	912	486	179
Non-residential	2798	2759	715	594	445	283	170
All buildings	4806	4654	2407	1907	1358	770	348

Table 24. Projected evolution in annual energy bill savings (€ million) for the EU West region building stock for the *EPBD compliant* compared with the *EPBD compliant without BACS* scenario

Building type	2020	2025	2030	2035	2040	2045	2050
All buildings	7440	19829	20822	20995	19964	17653	14826

5. Summary & conclusions

The recast EPBD can be considered to be the first time the EU has applied policy measures to promote energy savings from BACS in a holistic manner. The aim of this study is to model the impact of the recast EPBD provisions for BACS to determine the impact that the BACS measures would be expected to deliver assuming that they are fully implemented. This is intended to complement the findings from the broader recast EPBD impact assessment which did not explicitly address the energy savings and other impacts related exclusively to the BACS-related policy measures.

In general, it finds that if fully respected the BACS related policy measures would be expected to produce very substantial energy savings in the EU building stock, namely 14% of the building stock's primary energy consumption. The value of the energy savings which would be attained are approximately 9 times the cost of the investments required and hence are highly cost-effective. Even so these are not the maximum savings that can be attained by the deployment of more efficient BACS in Europe's buildings, as on average these measures are roughly associated with bringing the BACS used in the European building stock up to the current energy performance class B level. Greater savings again could be attained were stronger measures to be pursued. Nonetheless, the projected savings are very substantial and justify the focus given to addressing this aspect in the recast EPBD.

For these savings to be realised it will be necessary for Member States to implement the relevant provisions from the EPBD appropriately.

Appendix A: Common HVAC control functions[11]

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.

[11] Text in this appendix is repeated from WSE (2014)

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. BACS will also increasingly be used to optimise the energy mix in the building e.g. heat pumps could be operated if local PV-power, or nearby wind power is available.

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, and improve efficiency

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: A primer on BACS[12]

This appendix provides a short primer on BACS. The text is duplicated from WSE (2014).

The technical buildings systems that can be controlled by BACS

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.

[12] Text in this appendix is repeated from WSE (2014)

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.

From this list the principle technical building systems (TBSs) mentioned in the EBPD and addressed in Article 8, are heating, cooling, lighting and hot water. In non-residential buildings controlled ventilation is also especially important and makes a significant contribution to the most building's energy consumption and overall energy balance.

In addition to this list of energy uses shading devices are also an important means of regulating solar loads in buildings and of preventing glare and if these are moveable or adaptable (rather than purely passive) then they are suitable for control by BACS too.

EN15232 – the BACS factor methodology

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.

The benefits of BACS

The benefits of correctly designed, installed and operated BACS 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 BACS are that they allow 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[13]
- 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.

HEMS

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

[13] 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.

- **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 BACS/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.

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.

Appendix C: Average stock EN15232 BACS factors by region and scenario

This appendix reports the building stock-averaged BACS factors derived for each policy scenario for each region (North, West, South), each building type (SFH=single family housing, MFH = multi-family housing, Office, Wholesale/Retail, Education, Hospital/Healthcare, Hotels, Restaurants, Entertainment/Other), and each technical building system (Space heating, Hot water, Cooling, Ventilation, Lighting, Space heating pumps, Hot water pumps). Note, a BACS factor of 1 corresponds to a class C performance under EN15232, thus stock-averaged values of above 1 are less efficient than class C and stock-average values of below 1 are more efficient than class C.

The building stock average values reported in the tables below are reported for each of the three scenarios assessed in this analysis: *EPBD compliant without BACS*, *EPBD compliant* (with BACS), and the *Frozen BACS* scenarios.

North Region

EPBD compliant without BACS								
SFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.031	1.023	1.005	0.988	0.971	0.956	0.941	0.927
hot water	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.096
cooling	1.178	1.175	1.168	1.161	1.155	1.148	1.141	1.135
ventilation	1.081	1.080	1.077	1.074	1.071	1.068	1.065	1.062
lighting	1.080	1.079	1.077	1.074	1.072	1.070	1.068	1.065
space heating pumps	1.016	1.013	1.005	0.998	0.991	0.984	0.977	0.970
hot water pumps	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.089
MFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.031	1.023	1.004	0.986	0.969	0.953	0.938	0.924
hot water	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.096
cooling	1.168	1.165	1.158	1.151	1.144	1.138	1.131	1.124
ventilation	1.081	1.080	1.077	1.074	1.071	1.068	1.065	1.136
lighting	1.080	1.079	1.077	1.074	1.072	1.070	1.068	1.065
space heating pumps	1.016	1.013	1.005	0.998	0.991	0.984	0.977	0.970
hot water pumps	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.089
Offices	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.283	1.265	1.222	1.181	1.143	1.107	1.073	1.041
hot water	1.032	1.029	1.023	1.016	1.009	1.002	0.995	0.994
cooling	1.185	1.165	1.115	1.067	1.022	0.979	0.939	0.902
ventilation	1.707	1.696	1.667	1.637	1.608	1.580	1.553	1.527
lighting	1.000	0.999	0.995	0.991	0.987	0.982	0.978	0.973
space heating pumps	1.158	1.150	1.132	1.114	1.097	1.080	1.065	1.049
hot water pumps	1.032	1.029	1.023	1.016	1.009	1.002	0.995	0.989
Wholesale/Retail	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.259	1.238	1.187	1.138	1.089	1.043	0.998	0.954
hot water	1.110	1.107	1.099	1.091	1.083	1.075	1.068	1.067
cooling	1.073	1.059	1.026	0.994	0.963	0.933	0.905	0.878
ventilation	1.616	1.609	1.592	1.573	1.554	1.536	1.518	1.500
lighting	1.000	0.999	0.996	0.993	0.990	0.987	0.983	0.979
space heating pumps	1.144	1.137	1.118	1.098	1.079	1.060	1.041	1.022
hot water pumps	1.110	1.107	1.099	1.091	1.083	1.075	1.068	1.060
Education	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.182	1.171	1.146	1.122	1.099	1.077	1.056	1.036
hot water	1.044	1.041	1.034	1.027	1.019	1.012	1.005	1.004
cooling	0.843	0.835	0.818	0.801	0.785	0.770	0.755	0.741
ventilation	1.551	1.546	1.532	1.518	1.505	1.492	1.480	1.468
lighting	1.000	0.999	0.996	0.993	0.990	0.987	0.983	0.979
space heating pumps	1.094	1.089	1.079	1.069	1.059	1.049	1.040	1.031

hot water pumps	1.044	1.041	1.034	1.026	1.019	1.012	1.005	0.998
Hospitals/Healthcare	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.035	1.027	1.009	0.992	0.976	0.961	0.947	0.933
hot water	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.965
cooling	0.638	0.633	0.623	0.613	0.604	0.595	0.587	0.579
ventilation	1.462	1.458	1.448	1.438	1.429	1.420	1.411	1.403
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.053	1.050	1.041	1.034	1.026	1.019	1.012	1.005
hot water pumps	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.961
Hotels	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.035	1.027	1.009	0.992	0.976	0.961	0.947	0.933
hot water	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.965
cooling	0.638	0.633	0.623	0.613	0.604	0.595	0.587	0.579
ventilation	1.462	1.458	1.448	1.438	1.429	1.420	1.411	1.403
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.053	1.050	1.041	1.034	1.026	1.019	1.012	1.005
hot water pumps	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.961
Restaurants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.035	1.027	1.009	0.992	0.976	0.961	0.947	0.933
hot water	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.965
cooling	0.638	0.633	0.623	0.613	0.604	0.595	0.587	0.579
ventilation	1.462	1.458	1.448	1.438	1.429	1.420	1.411	1.403
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.053	1.050	1.041	1.034	1.026	1.019	1.012	1.005
hot water pumps	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.961
Entertainment/other	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.184	1.170	1.135	1.102	1.071	1.041	1.012	0.985
hot water	1.044	1.041	1.034	1.027	1.019	1.012	1.005	1.004
cooling	1.304	1.283	1.235	1.189	1.145	1.103	1.063	1.025
ventilation	1.782	1.772	1.747	1.722	1.698	1.675	1.652	1.629
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.105	1.099	1.084	1.069	1.055	1.041	1.028	1.015
hot water pumps	1.044	1.041	1.034	1.026	1.019	1.012	1.005	0.998

EPBD compliant (with BACS)								
SFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.031	0.996	0.925	0.871	0.829	0.797	0.772	0.752
hot water	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.089
cooling	1.178	1.171	1.155	1.139	1.124	1.109	1.094	1.080
ventilation	1.081	1.079	1.075	1.071	1.067	1.063	1.059	1.055
lighting	1.080	1.079	1.076	1.073	1.070	1.067	1.064	1.061
space heating pumps	1.016	1.002	0.971	0.947	0.927	0.911	0.898	0.887
hot water pumps	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.082
MFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.031	0.985	0.896	0.834	0.790	0.759	0.736	0.720
hot water	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.090
cooling	1.168	1.161	1.145	1.129	1.113	1.098	1.084	1.070
ventilation	1.081	1.080	1.076	1.072	1.068	1.064	1.060	1.127
lighting	1.080	1.079	1.076	1.073	1.070	1.067	1.064	1.061
space heating pumps	1.016	0.998	0.961	0.933	0.912	0.896	0.884	0.875
hot water pumps	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.082
Offices	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.283	1.124	0.861	0.837	0.814	0.793	0.773	0.755
hot water	1.032	1.009	0.962	0.955	0.948	0.942	0.935	0.932
cooling	1.185	0.999	0.700	0.671	0.645	0.620	0.598	0.577
ventilation	1.707	1.605	1.418	1.393	1.368	1.345	1.322	1.301
lighting	1.000	0.978	0.933	0.925	0.918	0.911	0.904	0.897
space heating pumps	1.158	1.092	0.971	0.957	0.944	0.932	0.920	0.909
hot water pumps	1.032	1.007	0.962	0.955	0.948	0.942	0.935	0.929
Wholesale/Retail	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.259	1.039	0.670	0.632	0.596	0.563	0.532	0.503

hot water	1.110	1.077	1.011	1.002	0.994	0.986	0.978	0.974
cooling	1.073	0.947	0.735	0.711	0.689	0.668	0.649	0.630
ventilation	1.616	1.558	1.454	1.433	1.414	1.395	1.376	1.359
lighting	1.000	0.983	0.947	0.940	0.934	0.928	0.922	0.916
space heating pumps	1.144	1.069	0.923	0.900	0.877	0.855	0.833	0.812
hot water pumps	1.110	1.076	1.011	1.002	0.994	0.986	0.978	0.971
Education	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.182	1.085	0.919	0.902	0.887	0.872	0.858	0.846
hot water	1.044	1.019	0.967	0.960	0.953	0.946	0.940	0.937
cooling	0.843	0.774	0.654	0.642	0.631	0.620	0.610	0.601
ventilation	1.551	1.500	1.404	1.393	1.381	1.370	1.360	1.350
lighting	1.000	0.983	0.947	0.940	0.934	0.928	0.922	0.916
space heating pumps	1.094	1.055	0.984	0.975	0.967	0.959	0.952	0.944
hot water pumps	1.044	1.017	0.967	0.960	0.953	0.946	0.940	0.934
Hospitals/Healthcare	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.035	0.972	0.865	0.854	0.845	0.836	0.827	0.819
hot water	1.002	0.983	0.945	0.938	0.932	0.926	0.920	0.917
cooling	0.638	0.601	0.539	0.533	0.528	0.522	0.517	0.513
ventilation	1.462	1.429	1.370	1.362	1.355	1.348	1.342	1.336
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.053	1.026	0.976	0.970	0.965	0.959	0.954	0.950
hot water pumps	1.002	0.982	0.945	0.938	0.932	0.926	0.920	0.915
Hotels	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.035	0.972	0.865	0.854	0.845	0.836	0.827	0.819
hot water	1.002	0.983	0.945	0.938	0.932	0.926	0.920	0.917
cooling	0.638	0.601	0.539	0.533	0.528	0.522	0.517	0.513
ventilation	1.462	1.429	1.370	1.362	1.355	1.348	1.342	1.336
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.053	1.026	0.976	0.970	0.965	0.959	0.954	0.950
hot water pumps	1.002	0.982	0.945	0.938	0.932	0.926	0.920	0.915
Restaurants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.035	0.972	0.865	0.854	0.845	0.836	0.827	0.819
hot water	1.002	0.983	0.945	0.938	0.932	0.926	0.920	0.917
cooling	0.638	0.601	0.539	0.533	0.528	0.522	0.517	0.513
ventilation	1.462	1.429	1.370	1.362	1.355	1.348	1.342	1.336
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.053	1.026	0.976	0.970	0.965	0.959	0.954	0.950
hot water pumps	1.002	0.982	0.945	0.938	0.932	0.926	0.920	0.915
Entertainment/other	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.184	1.048	0.818	0.796	0.776	0.757	0.739	0.722
hot water	1.044	1.019	0.967	0.960	0.953	0.946	0.940	0.937
cooling	1.304	1.116	0.808	0.777	0.748	0.720	0.695	0.671
ventilation	1.782	1.696	1.540	1.516	1.492	1.468	1.446	1.424
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.105	1.046	0.936	0.924	0.912	0.901	0.891	0.881
hot water pumps	1.044	1.017	0.967	0.960	0.953	0.946	0.940	0.934

Frozen BACS scenario								
SFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031
hot water	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
cooling	1.178	1.178	1.178	1.178	1.178	1.178	1.178	1.178
ventilation	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081
lighting	1.080	1.080	1.080	1.080	1.080	1.080	1.080	1.080
space heating pumps	1.016	1.016	1.016	1.016	1.016	1.016	1.016	1.016
hot water pumps	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
MFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031
hot water	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
cooling	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168
ventilation	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081

lighting	1.080	1.080	1.080	1.080	1.080	1.080	1.080	1.080
space heating pumps	1.016	1.016	1.016	1.016	1.016	1.016	1.016	1.016
hot water pumps	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
Offices	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.283	1.283	1.283	1.283	1.283	1.283	1.283	1.283
hot water	1.032	1.032	1.032	1.032	1.032	1.032	1.032	1.030
cooling	1.185	1.185	1.185	1.185	1.185	1.185	1.185	1.185
ventilation	1.707	1.707	1.707	1.707	1.707	1.707	1.707	1.707
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.158	1.158	1.158	1.158	1.158	1.158	1.158	1.158
hot water pumps	1.032	1.032	1.032	1.032	1.032	1.032	1.032	1.032
Wholesale/Retail	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.259	1.259	1.259	1.259	1.259	1.259	1.259	1.259
hot water	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
cooling	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073
ventilation	1.616	1.616	1.616	1.616	1.616	1.616	1.616	1.616
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.144	1.144	1.144	1.144	1.144	1.144	1.144	1.144
hot water pumps	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
Education	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.182	1.182	1.182	1.182	1.182	1.182	1.182	1.182
hot water	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
cooling	0.843	0.843	0.843	0.843	0.843	0.843	0.843	0.843
ventilation	1.551	1.551	1.551	1.551	1.551	1.551	1.551	1.551
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.094	1.094	1.094	1.094	1.094	1.094	1.094	1.094
hot water pumps	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
Hospitals/Healthcare	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.035	1.035	1.035	1.035	1.035	1.035	1.035	1.035
hot water	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.000
cooling	0.638	0.638	0.638	0.638	0.638	0.638	0.638	0.638
ventilation	1.462	1.462	1.462	1.462	1.462	1.462	1.462	1.462
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.053	1.053	1.053	1.053	1.053	1.053	1.053	1.053
hot water pumps	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
Hotels	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.035	1.035	1.035	1.035	1.035	1.035	1.035	1.035
hot water	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.000
cooling	0.638	0.638	0.638	0.638	0.638	0.638	0.638	0.638
ventilation	1.462	1.462	1.462	1.462	1.462	1.462	1.462	1.462
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.053	1.053	1.053	1.053	1.053	1.053	1.053	1.053
hot water pumps	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
Restaurants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.035	1.035	1.035	1.035	1.035	1.035	1.035	1.035
hot water	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.000
cooling	0.638	0.638	0.638	0.638	0.638	0.638	0.638	0.638
ventilation	1.462	1.462	1.462	1.462	1.462	1.462	1.462	1.462
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.053	1.053	1.053	1.053	1.053	1.053	1.053	1.053
hot water pumps	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
Entertainment/other	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.184	1.184	1.184	1.184	1.184	1.184	1.184	1.184
hot water	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
cooling	1.304	1.304	1.304	1.304	1.304	1.304	1.304	1.304
ventilation	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105
hot water pumps	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044

West region

EPBD compliant without BACS								
SFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.011	1.003	0.986	0.969	0.953	0.938	0.924	0.911
hot water	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.096
cooling	1.178	1.175	1.168	1.161	1.155	1.148	1.141	1.135
ventilation	1.081	1.080	1.077	1.074	1.071	1.068	1.065	1.062
lighting	1.080	1.079	1.077	1.074	1.072	1.070	1.068	1.065
space heating pumps	1.008	1.004	0.997	0.990	0.983	0.976	0.969	0.963
hot water pumps	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.089
MFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.010	1.002	0.984	0.967	0.951	0.936	0.921	0.907
hot water	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.096
cooling	1.168	1.165	1.158	1.151	1.144	1.138	1.131	1.124
ventilation	1.081	1.080	1.077	1.074	1.071	1.068	1.065	1.136
lighting	1.080	1.079	1.077	1.074	1.072	1.070	1.068	1.065
space heating pumps	1.008	1.004	0.997	0.990	0.983	0.976	0.969	0.963
hot water pumps	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.089
Offices	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.276	1.258	1.216	1.176	1.138	1.102	1.068	1.037
hot water	1.032	1.029	1.023	1.016	1.009	1.002	0.995	0.994
cooling	1.185	1.165	1.115	1.067	1.022	0.979	0.939	0.902
ventilation	1.707	1.695	1.664	1.632	1.601	1.571	1.542	1.513
lighting	1.000	0.999	0.995	0.991	0.987	0.982	0.978	0.973
space heating pumps	1.155	1.147	1.129	1.111	1.094	1.078	1.062	1.047
hot water pumps	1.032	1.029	1.023	1.016	1.009	1.002	0.995	0.989
Wholesale/Retail	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.245	1.224	1.172	1.122	1.074	1.027	0.982	0.938
hot water	1.110	1.107	1.099	1.091	1.083	1.075	1.068	1.067
cooling	1.073	1.059	1.026	0.994	0.963	0.933	0.905	0.878
ventilation	1.616	1.608	1.590	1.570	1.550	1.530	1.511	1.492
lighting	1.000	0.999	0.996	0.993	0.990	0.987	0.983	0.979
space heating pumps	1.138	1.130	1.111	1.092	1.072	1.053	1.034	1.015
hot water pumps	1.110	1.107	1.099	1.091	1.083	1.075	1.068	1.060
Education	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.182	1.171	1.146	1.122	1.099	1.077	1.056	1.036
hot water	1.044	1.041	1.034	1.027	1.019	1.012	1.005	1.004
cooling	0.843	0.835	0.818	0.801	0.785	0.770	0.755	0.741
ventilation	1.551	1.545	1.531	1.516	1.502	1.488	1.474	1.461
lighting	1.000	0.999	0.996	0.993	0.990	0.987	0.983	0.979
space heating pumps	1.094	1.089	1.079	1.069	1.059	1.049	1.040	1.031
hot water pumps	1.044	1.041	1.034	1.026	1.019	1.012	1.005	0.998
Hospitals/Healthcare	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.009	1.003	0.986	0.970	0.956	0.942	0.929	0.916
hot water	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.965
cooling	0.638	0.633	0.623	0.613	0.604	0.595	0.587	0.579
ventilation	1.462	1.457	1.447	1.437	1.426	1.417	1.407	1.398
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.044	1.041	1.033	1.025	1.018	1.011	1.004	0.998
hot water pumps	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.961
Hotels	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.009	1.003	0.986	0.970	0.956	0.942	0.929	0.916
hot water	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.965
cooling	0.638	0.633	0.623	0.613	0.604	0.595	0.587	0.579
ventilation	1.462	1.457	1.447	1.437	1.426	1.417	1.407	1.398
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.044	1.041	1.033	1.025	1.018	1.011	1.004	0.998
hot water pumps	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.961
Restaurants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.009	1.003	0.986	0.970	0.956	0.942	0.929	0.916

hot water	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.965
cooling	0.638	0.633	0.623	0.613	0.604	0.595	0.587	0.579
ventilation	1.462	1.457	1.447	1.437	1.426	1.417	1.407	1.398
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.044	1.041	1.033	1.025	1.018	1.011	1.004	0.998
hot water pumps	1.002	1.000	0.994	0.987	0.980	0.974	0.967	0.961
Entertainment/other	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.184	1.170	1.135	1.102	1.071	1.041	1.012	0.985
hot water	1.044	1.041	1.034	1.027	1.019	1.012	1.005	1.004
cooling	1.304	1.283	1.235	1.189	1.145	1.103	1.063	1.025
ventilation	1.782	1.771	1.744	1.718	1.692	1.666	1.642	1.617
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.105	1.099	1.084	1.069	1.055	1.041	1.028	1.015
hot water pumps	1.044	1.041	1.034	1.026	1.019	1.012	1.005	0.998

EPBD compliant (with BACS)								
SFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.011	0.978	0.911	0.859	0.820	0.790	0.766	0.747
hot water	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.089
cooling	1.178	1.171	1.155	1.139	1.124	1.109	1.094	1.080
ventilation	1.081	1.079	1.075	1.071	1.067	1.063	1.059	1.055
lighting	1.080	1.079	1.076	1.073	1.070	1.067	1.064	1.061
space heating pumps	1.008	0.994	0.965	0.942	0.923	0.908	0.895	0.885
hot water pumps	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.082
MFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.010	0.967	0.883	0.825	0.783	0.754	0.732	0.717
hot water	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.090
cooling	1.168	1.161	1.145	1.129	1.113	1.098	1.084	1.070
ventilation	1.081	1.080	1.076	1.072	1.068	1.064	1.060	1.127
lighting	1.080	1.079	1.076	1.073	1.070	1.067	1.064	1.061
space heating pumps	1.008	0.990	0.955	0.928	0.909	0.894	0.882	0.873
hot water pumps	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.082
Offices	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.276	1.119	0.859	0.834	0.812	0.791	0.771	0.753
hot water	1.032	1.009	0.962	0.955	0.948	0.942	0.935	0.932
cooling	1.185	0.999	0.700	0.671	0.645	0.620	0.598	0.577
ventilation	1.707	1.597	1.396	1.368	1.342	1.317	1.292	1.269
lighting	1.000	0.978	0.933	0.925	0.918	0.911	0.904	0.897
space heating pumps	1.155	1.089	0.969	0.955	0.942	0.930	0.918	0.907
hot water pumps	1.032	1.007	0.962	0.955	0.948	0.942	0.935	0.929
Wholesale/Retail	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.245	1.026	0.661	0.623	0.588	0.555	0.525	0.496
hot water	1.110	1.077	1.011	1.002	0.994	0.986	0.978	0.974
cooling	1.073	0.947	0.735	0.711	0.689	0.668	0.649	0.630
ventilation	1.616	1.553	1.441	1.419	1.398	1.378	1.358	1.339
lighting	1.000	0.983	0.947	0.940	0.934	0.928	0.922	0.916
space heating pumps	1.138	1.063	0.918	0.894	0.872	0.850	0.828	0.808
hot water pumps	1.110	1.076	1.011	1.002	0.994	0.986	0.978	0.971
Education	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.182	1.085	0.919	0.902	0.887	0.872	0.858	0.846
hot water	1.044	1.019	0.967	0.960	0.953	0.946	0.940	0.937
cooling	0.843	0.774	0.654	0.642	0.631	0.620	0.610	0.601
ventilation	1.551	1.496	1.393	1.380	1.368	1.356	1.345	1.334
lighting	1.000	0.983	0.947	0.940	0.934	0.928	0.922	0.916
space heating pumps	1.094	1.055	0.984	0.975	0.967	0.959	0.952	0.944
hot water pumps	1.044	1.017	0.967	0.960	0.953	0.946	0.940	0.934
Hospitals/Healthcare	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.009	0.952	0.853	0.844	0.835	0.826	0.819	0.811
hot water	1.002	0.983	0.945	0.938	0.932	0.926	0.920	0.917
cooling	0.638	0.601	0.539	0.533	0.528	0.522	0.517	0.513
ventilation	1.462	1.426	1.363	1.355	1.347	1.340	1.333	1.326

lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.044	1.018	0.972	0.966	0.961	0.956	0.951	0.946
hot water pumps	1.002	0.982	0.945	0.938	0.932	0.926	0.920	0.915
Hotels	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.009	0.952	0.853	0.844	0.835	0.826	0.819	0.811
hot water	1.002	0.983	0.945	0.938	0.932	0.926	0.920	0.917
cooling	0.638	0.601	0.539	0.533	0.528	0.522	0.517	0.513
ventilation	1.462	1.426	1.363	1.355	1.347	1.340	1.333	1.326
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.044	1.018	0.972	0.966	0.961	0.956	0.951	0.946
hot water pumps	1.002	0.982	0.945	0.938	0.932	0.926	0.920	0.915
Restaurants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.009	0.952	0.853	0.844	0.835	0.826	0.819	0.811
hot water	1.002	0.983	0.945	0.938	0.932	0.926	0.920	0.917
cooling	0.638	0.601	0.539	0.533	0.528	0.522	0.517	0.513
ventilation	1.462	1.426	1.363	1.355	1.347	1.340	1.333	1.326
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.044	1.018	0.972	0.966	0.961	0.956	0.951	0.946
hot water pumps	1.002	0.982	0.945	0.938	0.932	0.926	0.920	0.915
Entertainment/other	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.184	1.048	0.818	0.796	0.776	0.757	0.739	0.722
hot water	1.044	1.019	0.967	0.960	0.953	0.946	0.940	0.937
cooling	1.304	1.116	0.808	0.777	0.748	0.720	0.695	0.671
ventilation	1.782	1.690	1.522	1.495	1.469	1.444	1.420	1.397
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.105	1.046	0.936	0.924	0.912	0.901	0.891	0.881
hot water pumps	1.044	1.017	0.967	0.960	0.953	0.946	0.940	0.934

Frozen BACS scenario								
SFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011
hot water	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
cooling	1.178	1.178	1.178	1.178	1.178	1.178	1.178	1.178
ventilation	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081
lighting	1.080	1.080	1.080	1.080	1.080	1.080	1.080	1.080
space heating pumps	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.008
hot water pumps	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
MFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010
hot water	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
cooling	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168
ventilation	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081
lighting	1.080	1.080	1.080	1.080	1.080	1.080	1.080	1.080
space heating pumps	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.008
hot water pumps	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
Offices	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.276	1.276	1.276	1.276	1.276	1.276	1.276	1.276
hot water	1.032	1.032	1.032	1.032	1.032	1.032	1.032	1.030
cooling	1.185	1.185	1.185	1.185	1.185	1.185	1.185	1.185
ventilation	1.707	1.707	1.707	1.707	1.707	1.707	1.707	1.707
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.155	1.155	1.155	1.155	1.155	1.155	1.155	1.155
hot water pumps	1.032	1.032	1.032	1.032	1.032	1.032	1.032	1.032
Wholesale/Retail	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.245	1.245	1.245	1.245	1.245	1.245	1.245	1.245
hot water	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
cooling	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073
ventilation	1.616	1.616	1.616	1.616	1.616	1.616	1.616	1.616
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.138	1.138	1.138	1.138	1.138	1.138	1.138	1.138
hot water pumps	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110

Education	2015	2020	2025	2030	2035	2040	2045	2050
space heating	1.182	1.182	1.182	1.182	1.182	1.182	1.182	1.182
hot water	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
cooling	0.843	0.843	0.843	0.843	0.843	0.843	0.843	0.843
ventilation	1.551	1.551	1.551	1.551	1.551	1.551	1.551	1.551
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.094	1.094	1.094	1.094	1.094	1.094	1.094	1.094
hot water pumps	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
Hospitals/Healthcare	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009
hot water	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.000
cooling	0.638	0.638	0.638	0.638	0.638	0.638	0.638	0.638
ventilation	1.462	1.462	1.462	1.462	1.462	1.462	1.462	1.462
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
hot water pumps	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
Hotels	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009
hot water	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.000
cooling	0.638	0.638	0.638	0.638	0.638	0.638	0.638	0.638
ventilation	1.462	1.462	1.462	1.462	1.462	1.462	1.462	1.462
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
hot water pumps	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
Restaurants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009
hot water	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.000
cooling	0.638	0.638	0.638	0.638	0.638	0.638	0.638	0.638
ventilation	1.462	1.462	1.462	1.462	1.462	1.462	1.462	1.462
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
hot water pumps	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
Entertainment/other	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.184	1.184	1.184	1.184	1.184	1.184	1.184	1.184
hot water	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
cooling	1.304	1.304	1.304	1.304	1.304	1.304	1.304	1.304
ventilation	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105
hot water pumps	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044

South Region

EPBD compliant without BACS								
SFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.049	1.042	1.024	1.007	0.990	0.975	0.960	0.946
hot water	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.096
cooling	1.178	1.175	1.168	1.161	1.155	1.148	1.141	1.135
ventilation	1.081	1.080	1.077	1.074	1.071	1.068	1.065	1.062
lighting	1.080	1.079	1.077	1.074	1.072	1.070	1.068	1.065
space heating pumps	1.025	1.022	1.014	1.007	1.000	0.993	0.986	0.979
hot water pumps	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.089
MFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.049	1.041	1.023	1.005	0.989	0.973	0.957	0.943
hot water	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.096
cooling	1.168	1.165	1.158	1.151	1.144	1.138	1.131	1.124
ventilation	1.081	1.080	1.077	1.074	1.071	1.068	1.065	1.136
lighting	1.080	1.079	1.077	1.074	1.072	1.070	1.068	1.065

space heating pumps	1.025	1.022	1.014	1.007	1.000	0.993	0.986	0.979
hot water pumps	1.110	1.109	1.105	1.102	1.099	1.095	1.092	1.089
Offices	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.449	1.427	1.375	1.326	1.279	1.236	1.194	1.155
hot water	1.050	1.047	1.040	1.033	1.026	1.019	1.012	1.010
cooling	1.327	1.302	1.243	1.187	1.135	1.085	1.039	0.995
ventilation	1.790	1.776	1.742	1.707	1.674	1.641	1.610	1.580
lighting	1.000	0.999	0.995	0.991	0.987	0.982	0.978	0.973
space heating pumps	1.225	1.216	1.195	1.175	1.156	1.137	1.119	1.102
hot water pumps	1.050	1.047	1.040	1.033	1.026	1.018	1.011	1.005
Wholesale/Retail	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.259	1.238	1.187	1.138	1.089	1.043	0.998	0.954
hot water	1.110	1.107	1.099	1.091	1.083	1.075	1.068	1.067
cooling	1.073	1.059	1.026	0.994	0.963	0.933	0.905	0.878
ventilation	1.616	1.608	1.590	1.570	1.550	1.530	1.511	1.492
lighting	1.000	0.999	0.996	0.993	0.990	0.987	0.983	0.979
space heating pumps	1.144	1.137	1.118	1.098	1.079	1.060	1.041	1.022
hot water pumps	1.110	1.107	1.099	1.091	1.083	1.075	1.068	1.060
Education	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.182	1.171	1.146	1.122	1.099	1.077	1.056	1.036
hot water	1.044	1.041	1.034	1.027	1.019	1.012	1.005	1.004
cooling	0.856	0.848	0.830	0.813	0.796	0.780	0.764	0.750
ventilation	1.551	1.545	1.531	1.516	1.502	1.488	1.474	1.461
lighting	1.000	0.999	0.996	0.993	0.990	0.987	0.983	0.979
space heating pumps	1.094	1.089	1.079	1.069	1.059	1.049	1.040	1.031
hot water pumps	1.044	1.041	1.034	1.026	1.019	1.012	1.005	0.998
Hospitals/Healthcare	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.106	1.096	1.075	1.054	1.035	1.017	0.999	0.983
hot water	1.031	1.029	1.022	1.015	1.008	1.001	0.994	0.992
cooling	0.681	0.676	0.663	0.651	0.640	0.629	0.619	0.609
ventilation	1.502	1.497	1.485	1.473	1.461	1.450	1.439	1.429
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.085	1.081	1.072	1.062	1.054	1.045	1.037	1.030
hot water pumps	1.031	1.029	1.022	1.015	1.007	1.001	0.994	0.987
Hotels	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.106	1.096	1.075	1.054	1.035	1.017	0.999	0.983
hot water	1.031	1.029	1.022	1.015	1.008	1.001	0.994	0.992
cooling	0.681	0.676	0.663	0.651	0.640	0.629	0.619	0.609
ventilation	1.502	1.497	1.485	1.473	1.461	1.450	1.439	1.429
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.085	1.081	1.072	1.062	1.054	1.045	1.037	1.030
hot water pumps	1.031	1.029	1.022	1.015	1.007	1.001	0.994	0.987
Restaurants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.106	1.096	1.075	1.054	1.035	1.017	0.999	0.983
hot water	1.031	1.029	1.022	1.015	1.008	1.001	0.994	0.992
cooling	0.681	0.676	0.663	0.651	0.640	0.629	0.619	0.609
ventilation	1.502	1.497	1.485	1.473	1.461	1.450	1.439	1.429
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.085	1.081	1.072	1.062	1.054	1.045	1.037	1.030
hot water pumps	1.031	1.029	1.022	1.015	1.007	1.001	0.994	0.987
Entertainment/other	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.184	1.170	1.135	1.102	1.071	1.041	1.012	0.985
hot water	1.044	1.041	1.034	1.027	1.019	1.012	1.005	1.004
cooling	1.304	1.283	1.235	1.189	1.145	1.103	1.063	1.025
ventilation	1.782	1.771	1.744	1.718	1.692	1.666	1.642	1.617
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.105	1.099	1.084	1.069	1.055	1.041	1.028	1.015
hot water pumps	1.044	1.041	1.034	1.026	1.019	1.012	1.005	0.998

EPBD compliant (with BACS)								
SFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**

space heating	1.049	1.014	0.940	0.884	0.840	0.806	0.779	0.758
hot water	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.089
cooling	1.178	1.171	1.155	1.139	1.124	1.109	1.094	1.080
ventilation	1.081	1.079	1.075	1.071	1.067	1.063	1.059	1.055
lighting	1.080	1.079	1.076	1.073	1.070	1.067	1.064	1.061
space heating pumps	1.025	1.010	0.979	0.953	0.933	0.916	0.902	0.891
hot water pumps	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.082
MFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.049	1.002	0.911	0.846	0.800	0.766	0.742	0.724
hot water	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.090
cooling	1.168	1.161	1.145	1.129	1.113	1.098	1.084	1.070
ventilation	1.081	1.080	1.076	1.072	1.068	1.064	1.060	1.127
lighting	1.080	1.079	1.076	1.073	1.070	1.067	1.064	1.061
space heating pumps	1.025	1.006	0.968	0.939	0.917	0.900	0.887	0.877
hot water pumps	1.110	1.108	1.104	1.099	1.095	1.091	1.086	1.082
Offices	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.449	1.254	0.934	0.904	0.877	0.851	0.828	0.806
hot water	1.050	1.025	0.973	0.965	0.958	0.951	0.945	0.941
cooling	1.327	1.107	0.757	0.724	0.694	0.666	0.640	0.616
ventilation	1.790	1.666	1.442	1.412	1.384	1.357	1.331	1.306
lighting	1.000	0.978	0.933	0.925	0.918	0.911	0.904	0.897
space heating pumps	1.225	1.148	1.007	0.991	0.977	0.963	0.949	0.937
hot water pumps	1.050	1.023	0.973	0.965	0.958	0.951	0.945	0.938
Wholesale/Retail	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.259	1.039	0.670	0.632	0.596	0.563	0.532	0.503
hot water	1.110	1.077	1.011	1.002	0.994	0.986	0.978	0.974
cooling	1.073	0.947	0.735	0.711	0.689	0.668	0.649	0.630
ventilation	1.616	1.553	1.441	1.419	1.398	1.378	1.358	1.339
lighting	1.000	0.983	0.947	0.940	0.934	0.928	0.922	0.916
space heating pumps	1.144	1.069	0.923	0.900	0.877	0.855	0.833	0.812
hot water pumps	1.110	1.076	1.011	1.002	0.994	0.986	0.978	0.971
Education	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.182	1.085	0.919	0.902	0.887	0.872	0.858	0.846
hot water	1.044	1.019	0.967	0.960	0.953	0.946	0.940	0.937
cooling	0.856	0.784	0.660	0.647	0.636	0.625	0.614	0.605
ventilation	1.551	1.496	1.393	1.380	1.368	1.356	1.345	1.334
lighting	1.000	0.983	0.947	0.940	0.934	0.928	0.922	0.916
space heating pumps	1.094	1.055	0.984	0.975	0.967	0.959	0.952	0.944
hot water pumps	1.044	1.017	0.967	0.960	0.953	0.946	0.940	0.934
Hospitals/Healthcare	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.106	1.029	0.898	0.886	0.874	0.863	0.853	0.843
hot water	1.031	1.008	0.961	0.954	0.947	0.940	0.934	0.931
cooling	0.681	0.636	0.559	0.552	0.545	0.539	0.533	0.527
ventilation	1.502	1.459	1.382	1.373	1.365	1.357	1.349	1.341
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.085	1.052	0.993	0.986	0.980	0.974	0.968	0.962
hot water pumps	1.031	1.006	0.960	0.953	0.947	0.940	0.934	0.928
Hotels	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.106	1.029	0.898	0.886	0.874	0.863	0.853	0.843
hot water	1.031	1.008	0.961	0.954	0.947	0.940	0.934	0.931
cooling	0.681	0.636	0.559	0.552	0.545	0.539	0.533	0.527
ventilation	1.502	1.459	1.382	1.373	1.365	1.357	1.349	1.341
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.085	1.052	0.993	0.986	0.980	0.974	0.968	0.962
hot water pumps	1.031	1.006	0.960	0.953	0.947	0.940	0.934	0.928
Restaurants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.106	1.029	0.898	0.886	0.874	0.863	0.853	0.843
hot water	1.031	1.008	0.961	0.954	0.947	0.940	0.934	0.931
cooling	0.681	0.636	0.559	0.552	0.545	0.539	0.533	0.527
ventilation	1.502	1.459	1.382	1.373	1.365	1.357	1.349	1.341
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

space heating pumps	1.085	1.052	0.993	0.986	0.980	0.974	0.968	0.962
hot water pumps	1.031	1.006	0.960	0.953	0.947	0.940	0.934	0.928
Entertainment/other	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.184	1.048	0.818	0.796	0.776	0.757	0.739	0.722
hot water	1.044	1.019	0.967	0.960	0.953	0.946	0.940	0.937
cooling	1.304	1.116	0.808	0.777	0.748	0.720	0.695	0.671
ventilation	1.782	1.690	1.522	1.495	1.469	1.444	1.420	1.397
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.105	1.046	0.936	0.924	0.912	0.901	0.891	0.881
hot water pumps	1.044	1.017	0.967	0.960	0.953	0.946	0.940	0.934

Frozen BACS scenario								
SFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.049	1.049	1.049	1.049	1.049	1.049	1.049	1.049
hot water	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
cooling	1.178	1.178	1.178	1.178	1.178	1.178	1.178	1.178
ventilation	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081
lighting	1.080	1.080	1.080	1.080	1.080	1.080	1.080	1.080
space heating pumps	1.025	1.025	1.025	1.025	1.025	1.025	1.025	1.025
hot water pumps	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
MFH	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.049	1.049	1.049	1.049	1.049	1.049	1.049	1.049
hot water	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
cooling	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168
ventilation	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081
lighting	1.080	1.080	1.080	1.080	1.080	1.080	1.080	1.080
space heating pumps	1.025	1.025	1.025	1.025	1.025	1.025	1.025	1.025
hot water pumps	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
Offices	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.449	1.449	1.449	1.449	1.449	1.449	1.449	1.449
hot water	1.050	1.050	1.050	1.050	1.050	1.050	1.050	1.050
cooling	1.327	1.327	1.327	1.327	1.327	1.327	1.327	1.327
ventilation	1.790	1.790	1.790	1.790	1.790	1.790	1.790	1.790
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.225	1.225	1.225	1.225	1.225	1.225	1.225	1.225
hot water pumps	1.050	1.050	1.050	1.050	1.050	1.050	1.050	1.050
Wholesale/Retail	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.259	1.259	1.259	1.259	1.259	1.259	1.259	1.259
hot water	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
cooling	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073
ventilation	1.616	1.616	1.616	1.616	1.616	1.616	1.616	1.616
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.144	1.144	1.144	1.144	1.144	1.144	1.144	1.144
hot water pumps	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
Education	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.182	1.182	1.182	1.182	1.182	1.182	1.182	1.182
hot water	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
cooling	0.856	0.856	0.856	0.856	0.856	0.856	0.856	0.856
ventilation	1.551	1.551	1.551	1.551	1.551	1.551	1.551	1.551
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.094	1.094	1.094	1.094	1.094	1.094	1.094	1.094
hot water pumps	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
Hospitals/Healthcare	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106
hot water	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031
cooling	0.681	0.681	0.681	0.681	0.681	0.681	0.681	0.681
ventilation	1.502	1.502	1.502	1.502	1.502	1.502	1.502	1.502
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.085	1.085	1.085	1.085	1.085	1.085	1.085	1.085
hot water pumps	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031
Hotels	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**

space heating	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106
hot water	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031
cooling	0.681	0.681	0.681	0.681	0.681	0.681	0.681	0.681
ventilation	1.502	1.502	1.502	1.502	1.502	1.502	1.502	1.502
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.085	1.085	1.085	1.085	1.085	1.085	1.085	1.085
hot water pumps	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031
Restaurants	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106
hot water	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031
cooling	0.681	0.681	0.681	0.681	0.681	0.681	0.681	0.681
ventilation	1.502	1.502	1.502	1.502	1.502	1.502	1.502	1.502
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.085	1.085	1.085	1.085	1.085	1.085	1.085	1.085
hot water pumps	1.031	1.031	1.031	1.031	1.031	1.031	1.031	1.031
Entertainment/other	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
space heating	1.184	1.184	1.184	1.184	1.184	1.184	1.184	1.184
hot water	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
cooling	1.304	1.304	1.304	1.304	1.304	1.304	1.304	1.304
ventilation	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782
lighting	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
space heating pumps	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105
hot water pumps	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044

References and further reading

Building Observatory (2019) https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/eubuildings

CEN (2008) *EN 15316-4-2:2008 Heating systems in buildings. Method for calculation of system efficiencies*, Comité European de Normalisation

CEN (2017) *EN 15232:2017. Energy performance of buildings. Impact of building automation, controls and building management*, Comité European de Normalisation

EC (2002) *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings*, European Commission

EC (2010a) *Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products*, European Commission

EC (2010) *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*, European Commission

EC (2012a) *Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements*, European Commission

EC (2012b) *Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements* (2012/C 115/01), European Commission

EC (2012c) *Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC*, European Commission

ECI (2017) *Employment benefits from stimulation of demand for building automation and controls in the EU*, http://www.leonardo-energy.org/resources/1247/employment-benefitsfrom-stimulation-of-demand-for-building--59ef3f74038bd

EC (2018) *Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.156.01.0075.01.ENG

EC (2019) Commission guidance on how to implement revised Energy Performance of Buildings Directive provisions on building renovation https://ec.europa.eu/info/news/commission-guidance-how-implement-revised-energy-performance-buildings-directive-provisions-building-renovation-2019-may-16_en

ECOFYS (2016) *Ex-ante evaluation and assessment of policy options for the EPBD*, Final report for EC DG-ENER.

ECOFYS & WSE (2017) *Optimising the energy use of technical building systems – unleashing the power of the EPBD's Article 8*, https://www.ecofys.com/files/files/ecofys-2017-optimising-theenergy-use-of-tbs-final-report.pdf eu.bac (2017) *Room temperature controls: How the EU is missing an opportunity for substantial energy savings* https://www.eubac.org/cms/upload/downloads/position_papers/White_Paper_on_Room_Temperature_Controls_-_eu.bac_July_2017_FINAL.pdf

Oschatz et al (2017) "*Kurzstudie Energieeinsparungen Digitale Heizung*" Short Study on Energy Savings from Digital Heating (in German only), Prof Oschatz, Prof. Hartmann, Prof. Werdin, Prof. Felsmann Institut für Technische Gebäudeausrüstung Dresden https://www.bdh-koeln.de/fileadmin/user_upload/Studien/energieeinsparungen_digitale_heizung_2017_01_12.pdf

VITO *et al* (2018) *Support for Setting-up A Smart Readiness Indicator for Buildings and Related Impact Assessment: Final Report*, VITO, Waide Strategic Efficiency, Ecofys, Offis for DG Energy, https://smartreadinessindicator.eu/1st-technical-study-outcome

VITO-WSE (2018) *Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 -2019: Task report on scoping*, VITO and Waide Strategic Efficiency, N° ENER/C3/FV 2017-438/04/FWC 2015-619 LOT1/01 for the conclusion of a specific contract in application of the Framework Contract No ENER/C3/2015-619 LOT 1 for European Commission Directorate-General for Energy, 20th July 2018

WSE (2014) *Building Automation: the Scope for Energy and CO2 Savings in the EU*, Waide Strategic Efficiency Ltd, http://www.leonardo-energy.org/resources/249/building-automation-the-scope-forenergy-and-co2-savings-in--57f7a23e8b452

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