Optimising the energy use of technical building systems – unleashing the power of the EPBD's Article 8

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Foreword by Danfoss

Buildings stand at the centre of the energy transition, and full decarbonisation of the building stock by 2050 will be a crucial driver in meeting the ambitious targets set out in global climate agreements. We need to take a fresh look at the challenge of buildings and turn this into a growth opportunity.

This Ecofys study on the optimization of technical building systems (TBS) is therefore both timely and relevant. It shows how much we can save by applying a holistic approach to the generation, distribution and emission of energy inside buildings.

Before now, we lacked an estimate of the magnitude of this potential at the EU level. This Ecofys report provides strong evidence that there is a huge energy savings potential in upgrading the control of heating, cooling, ventilation, lighting and hot water systems inside our buildings. With the right investments, we could save an average of 30% on energy consumption in the buildings that will be renovated within the EU through 2030. The report also shows that by 2030 we could save up to 67 billion Euros per year on energy costs if TBS would be gradually and consistently retrofitted with high performance solutions across Europe.

This is good news for Europe: renovation of our building stock is more affordable than many currently believe.

Optimizing our technical building systems needs to take higher priority. The Ecofys report clearly shows what we need to do. If we get the basics right in our buildings, while leveraging new technologies, we can all reap the rewards of additional energy savings with modern, comfortable buildings.

It is time to work together to realize the potential of this giant economic and environmental opportunity.

Niels B. Christiansen
President & CEO Danfoss

A study initiated by

ENGINEERING TOMORROW Danfoss

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Executive Summary

The main objective of the proposed revision of the Energy Performance of Buildings Directive (EPBD) which the European Commission released on the 30th November 2016 "is to accelerate the cost-effective renovation of existing buildings." Acceleration is urgently needed. If rate and depth of energy efficiency improvements in existing building continue on a Business-As-Usual path a significant gap will remain both to the proposed binding 30% by 2030 energy efficiency target and to the massive reductions of greenhouse gas emissions for 2030 and 2050 as set out in the "Roadmap for moving to a competitive low-carbon economy in 2050".

This report wants to contribute to close that gap. Two central questions were to be answered:

1) How much can optimisation of the energy use of technical building systems (TBS), i.e. "technical equipment for heating, cooling, ventilation, hot water, lighting or for a combination thereof, of a building or building unit"[1], contribute to fill the gap until 2030?
2) What measures should be taken – with a focus on the ongoing revision of the EPBD - to let optimisation of TBS significantly help filling the gap till 2030?

Obviously question 2) is only relevant when optimisation of the energy use of technical building systems could provide significant energy savings and emissions reductions. After thorough analyses we can state: yes, it could. In a "Get the basics right" scenario we estimate an additional annual CO_2 reductions potential of roughly 60 Mt by 2030 compared to BAU just by consistent basic optimisation of TBS in existing buildings across the EU. To put this into perspective this outperforms the *total* CO_2 reductions potential (38 Mt) of the proposed revision of the EPBD by more than 50%, while it is roughly on par as to primary energy savings. Average payback for get the basics right packages of measures is just 2 years, additional annual energy cost savings amount to roughly 36 billion EUR by 2030. Significantly higher additional savings could be achieved in a world of "High Performance" measures which include advanced building automation and control measures on top of the basic optimisation. Provided that *High performance* packages would have a significant share in TBS optimisation till 2030 this would have an average savings potential of TBS packages of up to 30%.

Unfortunately, so far this potential seems to have been underestimated – and it has not been exploited, although the EPBD's Article 8 on "Technical Building systems" clearly tries to wake this sleeping giant. Yet Article 8 does not deliver yet. This is due to quite incomplete implementation and compliance at national level. Although required by Article 8, Member States largely lack clearly defined performance system requirements for any new, replacement and upgrade of technical building systems in existing buildings. There is also no common understanding about the kind of measures needed. Sometimes requirements only exist for *major* renovations rather than for *any* renovation of TBS in existing buildings, sometimes there are only requirements for single components of systems, rather than for the whole system.

[1] European Parliament and the Council of the European Union 2010

Immediate action should be taken to unleash the savings potential which lies in optimising the energy use of technical building systems. This is because optimisation of technical building systems quickly delivers cost-effective significant savings without creating lock-in effects. It also helps to close the performance gap often observed during stepwise renovation towards nearly zero-energy buildings (nZEB) and it supports the persistence of energy savings. Such optimisations could be implemented at a much higher renovation rate than its indispensable counterpart "building insulation", without hampering it. In this study we assumed an annual rate of 3.6% for the renovation of TBS, which seems to be reasonable and feasible, as it equals the estimated rate for the renewal of heat generators. Quick action also helps to reduce *cumulated* CO_2 emissions which is the ultimate target of climate policy.

Last but not least through advanced building automation and control systems (BACS), TBS become an active, manageable part of the energy system in transition, offering more flexibility options. This unlocks savings potentials beyond buildings' walls and increases the readiness of buildings for smart operation within the energy system, like a potential interaction of buildings and e-mobility.

Our main policy recommendations for unleashing the savings potential of TBS are as follows:

- The ongoing revision of the EPBD should be used to give a significant push to a substantial increase of rate and depth of technical building systems' optimisation in existing buildings.
- The ongoing revision of the EPBD should be used to provide more guidance on Article 8, including best practice examples for the enforcement of its implementation:
    - So far Article 8 does not link requirements to functionalities of TBS like the control of energy generation, distribution and emission of heating and cooling. Yet this might be a way to make "overall system performance requirements" more concrete.
    - Some of the very short payback, no-regret options could be explicitly made mandatory, accompanied by a deadline for implementation. In this context we would like to highlight controls for room temperature which in our opinion are a "conditio sine qua non" for empowering consumers to act on feedback from consumption based billing for space heat, which is required by the Energy Efficiency Directive.
    - Incentives like the current German grants for optimisation of heating systems.
- The Commission should encourage Member States to clearly address the most efficient order of measures in their national long-term renovation strategies. Due to the optimisation of TBS being a no-regret, short payback instrument it usually should rank high.
- The Commission should specifically provide further guidance on BACS for supporting their proper implementation, including best practice examples, guidance on cost-optimal solutions, and application for monitoring of the implementation of national renovation roadmaps.

Due to the very high ambition level of climate and energy efficiency targets the question is not which technological solution should dominate but how to integrate all available solutions in the best way for making the target. Both optimisation of TBS and the improvement of the energy performance of building envelopes are indispensable counterparts of each other for reaching a climate neutral building stock. As TBS were in the focus of this study we conclude that the optimisation of technical building systems in existing buildings offers a very attractive, no-regret potential to actually "accelerate the cost-effective renovation of existing buildings" across Europe immediately.

Definitions

Technical Building System (TBS)

"'Technical building system' means technical equipment for the heating, cooling, ventilation, hot water, lighting or for a combination thereof, of a building or building unit; …"
(Source: EPBD recast 2010, Article 2 (3.))[2]

Building Automation and Control System (BACS)

"System, comprising all products and engineering services for automatic controls (including interlocks), monitoring, optimisation, for operation, human intervention, and management to achieve energy – efficient, economical, and safe operation of building services.
NOTE 1 The use of the word 'control' does not imply that the system/device is restricted to control functions. Processing of data and information is possible.
NOTE 2 If a building control system, building management system, or building energy management system complies with the requirements of the EN ISO 16484 standard series, it should be designated as a building automation and control system (BACS)."
(Source: EN ISO 16484-2:2004, 3.31)

This means that according to *EN ISO 16484-2:2004, 3.31*[3]:

- Building Control System (BCS)
- Building Management System (BMS)
- Building Energy Management System (BEMS)

are to be considered as sub-sets of BACS, as long as they comply with the EN ISO 16484 standard series. Yet, colloquially the term "BACS" is frequently used interchangeably with BCS, BMS and BEMS and the like.[4]

In this study the focus is on the energy efficiency potential that can be exploited by optimization of technical building systems, including BACS. The starting point for these optimizations is a building, where the heat generator (e.g. old boiler) has just been replaced by a new heat generator (e.g. condensing boiler). This means the savings of such mere exchange of the heat generator are excluded, while savings that can be achieved by optimisation of the operational parameters of the new heat generator are included.

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[2] On 30 November 2016 the European Commission published their proposal for an update of the EPBD (COM(2016) 765 final) featuring the following updated definition: '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, on-site infrastructure for electro-mobility, or a combination of such systems, including those using energy from renewable sources, of a building or building unit;'
[3] https://www.designingbuildings.co.uk/wiki/Building_Automation_and_Control_System_BACS
[4] Further non EN ISO 16484 sub-sets like Building Automation Systems (BAS) are used in the discussion.

1 Introduction

1.1 Situation

Buildings are in the focus of energy policies in Europe for several reasons:

- Energy poverty could be alleviated significantly by more energy efficient buildings.
- Buildings have a major impact on the health and well-being of Europeans.
- Changing the supply mix of buildings offers a significant potential for more independency from energy imports [ECOFYS, 2014].
- The need for nearly-zero energy buildings in new construction but also in the building stock poses new challenges and chances for Member States and industry.
- Buildings are more and more required to be "smart", serving the need to add flexibility to an integrated energy system including electro—mobility by means of higher energy efficiency, advanced technologies and ICT.
- Yet it is widely acknowledged that a significant amount of cost-effective potentials for energy efficiency and renewable energy technologies won't be exploited till 2030 in a Business-as-Usual world.
- In such Business-as-Usual world, Europe's 2030 targets for energy efficiency but also long-term CO_2 reduction targets as set out in the EU Roadmap for moving to a low carbon economy [EC, 2011] will be missed.
- Improving the energy efficiency in buildings is key for reaching the European Union's 2030 and 2050 climate and energy efficiency targets.
- Especially the speed (renovation rate) and the quality (renovation depth) of renovating Europe's buildings need a significant push for meeting the targets.

These insights have guided the European Commission's proposal for a revision of the Energy Performance of Buildings Directive (EPBD). It was published on 30 November 2016 within the "Clean Energy for All Europeans" package. "Targeted amendments" to the EPBD are to remove barriers which hamper a faster take-up and full exploitation of cost-effective energy efficiency potentials.

Technical building systems (TBS) including building automation and control systems (BACS) play an important role in increasing the energy efficiency of buildings persistently, while providing them with more flexibility within the energy system and adding to the well-being of European's. This is why TBS play an important role in the proposed draft EPBD, too. There is consensus that a large untapped cost-effective savings potential lies within the optimisation of TBS that needs to be tackled.[5]

Currently, the EPBD defines technical building systems (TBS) as "*technical equipment for the heating, cooling, ventilation, hot water, lighting or for a combination thereof, of a building, or building unit" (EPBD, Art.2, 3.).* As a consequence of the increased importance for and stronger involvement in the

[5] For example, according to the EC's Impact Assessment of the EPBD, the use of building energy management systems (see definitions above) alone may reduce the energy consumption for space heating between 2-30% and for space cooling between 37-73%.

future energy system, the proposed revision of the EPBD also includes an update of the TBS definition now amongst others explicitly encompassing building automation and control as well as on-site infrastructure for electro-mobility.

While there are several ways to tackle the untapped savings potentials of TBS, the focus of this study will be on Article 8, EPBD "Technical building systems". This is because within the EPBD, Article 8 is the major provision for optimising the use of technical building systems for the benefit of improved energy efficiency of buildings. Article 8 (1) currently says:

> "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 system 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. […].*
> *The system requirements must cover at least (a) heating systems; (b) hot water systems; (c) air-conditioning systems; (d) large ventilation systems; or a combination of such systems.*"

Emphasis needs to be put on the fact, that *whenever* in *existing* buildings technical building systems are built new, replaced or upgraded the system requirements set by the respective Member State need to be fulfilled. Thus, Article 8 (1) is clearly not restricted to major renovations of existing buildings. Furthermore; according to Article 28 EPBD, Member States should have adopted and published by 9 July 2012 at the latest the laws, regulations and administrative provisions necessary to comply with Article 8, and applied those provisions to buildings occupied by the public authorities from 9 January 2013 at the latest and to other buildings from 9 July 2013 at the latest.

There is vast evidence that the potential of Article 8 and thus the savings potential lying in the optimisation of TBS is far from being fully exploited.[6] Although the proposed EPBD also includes amendments for Article 8 like the documentation of the overall energy performance of new, replaced and upgraded TBS in existing buildings, the discussion around the proposed Article 8 EPBD needs to explore how the current Article 8 has been implemented by Member States, why so far it has not delivered the expected reductions and how big these reductions actually could be. Such understanding is urgently needed for getting the basics of Article 8 right, and to tailor the amendments exactly the way needed to make Article 8 fully deliver its potential.

1.2 Goal and approach of the study

The overall goal of the study is a better understanding of the energy savings and CO_2 reductions potential lying in the optimisation of technical building systems and to propose policy recommendations for a better exploitation of this potential. The *additional* savings potential calculated within the scope of this study for an *optimisation* of TBS do not include the impact achieved by a

[6] For more details please see chapter 2.

mere replacement of the heat generator as this is assumed to be part of a Business-As-Usual path[7]. Yet the savings that can be achieved by optimizing the settings and operation of such new heat generator are included. The underlying questions are:

- Why have Member States so far not been able exploit the potential of Article 8? What needs to be done in order to let them actually achieve the good purpose mentioned in Article 8 of "optimising the energy use of technical building systems"?
- What kind of technical measures for optimising the energy use of technical building systems (TBS) are concretely spoken of?
- What energy savings could be achieved in typical individual European buildings by such optimisation of TBS?
- What additional energy savings and CO_2 reductions could be achieved on a European level just by the proper implementation of Article 8 (1), i.e. if such optimisation would exist whenever technical building systems in existing buildings are renewed, replaced or renovated?
- What would this mean in the context of the EPBD's contribution to the EU energy efficiency and climate targets?
- Which policy measures could be thought of in the course of the ongoing discussion about the proposal for revision of the EPBD, to untap this savings potential?

In order to provide answers to these questions the following steps will be taken:

- Provide some insight into the state of play of the actual implementation of Article 8 of the EPBD across the EU (chapter 2).
- Calculate potential savings of optimisation measures and optimisation packages of technical building systems in eight reference cases, i.e. buildings which represent typical European average residential and non-residential buildings (chapter 3).
- Extrapolate potential energy savings and CO_2 reductions calculated for the reference cases to the level of the European building stock and put these into the context of what the proposed EPBD is to deliver (chapter 4).
- Draw conclusions and develop ideas for potential policy measures that should help unleash the full potential lying in the optimisation of TBS, with a focus on Article 8(chapter 5).

Furthermore, an Annex provides details about input data used, the description of the optimisation measures and packages investigated, and provides detailed results and factsheets per reference case illustrating the optimisation potential of measures and packages.

[7] The replacxement of heat generators is assumed to happen at a rate of 3.6%%a as the baseline for additional savings that can be achieved by further optimizations.

2 Regulatory framework supporting the optimisation of technical building systems (TBS)

Several regulations to promote energy efficiency of technical building systems are currently in place on a European level:

- Article 1 c (iii) EPBD clearly requires "the application of minimum requirements to the energy performance of … technical building systems whenever they are installed, replaced or upgraded"
  - this puts an emphasis on TBS, as the overarching requirement in Article 1 for the application of minimum requirements to the energy performance of new buildings and existing buildings in practice will be met by both the building envelope and the technical building systems,
  - furthermore, it explicitly does not restrict requirements for technically building systems to new buildings or major renovations but to all cases where technical building systems are installed, replaced or upgraded ("whenever");
- Article 2 EPBD provides a definition for technical building systems including heating, cooling, ventilation, hot water, lighting or a combination thereof,
- Article 8 EPBD, "Technical building systems" asks for system requirements for technical building systems "which are installed in *existing* buildings".
- Article 14 and 15 EPBD set requirements for the inspection of heating systems and air conditioning systems.
- Ecodesign implementing regulations set efficiency requirements for products like boilers and pumps. As these will be used as parts within technical building systems they indirectly influence their efficiency.
- Energy labelling delegated regulations such as the one on space heaters.

Article 8 is the central regulatory measure promoting the optimisation of technical building systems. This is why in the following we focus on its implementation.[8]

2.1 Article 8 EPBD "Technical Building systems"

Article 8 EPBD "Technical building systems" is meant to be the central article to promote the exploitation of the untapped energy efficiency potential of technical building systems in all existing buildings.

[8] Information on the implementation of EPBD Article 14 and 15 on inspections of heating and cooling systems may be found in the reports of the Concerted Action EPBD.

Article 8 (1) currently says:

"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 system 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 […] The system requirements must cover at least (a) heating systems; (b) hot water systems; (c) air-conditioning systems; (d) large ventilation systems; or a combination of such systems.*"

Article 8 specifies what was already mentioned in Article 1: requirements need to be set for new, replacement and upgrading of technical building systems, i.e. not just in case of major renovations. Furthermore, these requirements "shall be applied in so far as they are technically, economically and functionally feasible". While Article 8 makes it mandatory for Member States to set system requirements for technical building systems in *existing* buildings, Member States only may do so in new buildings.

The following table provides a systematic overview about the *systems* that according to Article 8 *at least* need to be addressed[9] and the *aspects* that system requirements need to encompass for the purpose of optimising the energy use of technical building systems.

Table 1: Overview of (minimum) coverage of system requirements

	Heating	Domestic hot water	Air conditioning	Large ventilation systems	Combination of such systems (alternative)
Overall energy performance	x	x	x	x	
Proper installation	x	x	x	x	
Appropriate dimensioning	x	x	x	x	
Appropriate adjustment	x	x	x	x	
Appropriate control	x	x	x	x	

To avoid confusion, please note the difference between the "integrated" energy performance of *buildings* (Article 2 EPBD) (also called "whole" or "overall" building energy performance"), the energy performance of building *systems* and the individual performance of *products*, the latter being used

[9] lighting is not covered mandatorily by Article 8 although lighting is explicitly mentioned in the definition for TBS in Article 2 EPBD. Yet, Member States of course could include lighting in their TBS requirements, too, as the list of TBS in Article 8 is not-exhaustive („at least").

e.g. for energy labelling. The overall energy performance of a building is a product of the energy performances of the building envelope and of the technical building systems.

Please also note the terminology used in the EPBD which we also use here: a *system* is either a heating system, or a domestic hot water system, or an air-conditioning system or a large ventilation system. These systems consist of components/products. As

Table 1 shows, Article 8 also enables requirements for combinations of such systems.

2.2 State of play - the implementation of Article 8 is far from complete

To make a long story short we fully agree with a general conclusion about the implementation of Article 8 that has been drawn in the recent *Concerted Action Study*[10]:

"TBS are clearly defined by the EPBD and regulations must provide for their proper installation and performance in existing buildings, but MSs have given little attention to this part of the EPBD until recently. While progress has been made, coverage is by no means complete for all the requirements with all the technologies involved. 'Existing buildings' means all such buildings, not just those undergoing major renovation."

We draw our accord with this statement from analysing the chapters on technical building systems within the country reports in that Concerted Action publication and from additionally having conducted two interviews with experts from Germany and the Czech Republic.

A closer look at the country reports that the Concerted Action EPBD has produced, actually reveals a really sobering picture about the current status of the implementation of Article 8 across Europe. Recurring themes in several country reports are as follows:

- There are no requirements or any regulations for TBS efficiency as a whole.
- There are no system requirements at all, but rather requirements for elements, going down to trivialities that CE marking is required.
- TBS system requirements are set only for new buildings or major renovations or projects that require a building permit.
- Requirements are only applied when "main parts" are installed/replaced, meaning e.g. the boiler.
- There are lists of individual measures like insulation thickness of pipework, obligatory thermostatic radiator valves, time schedules for the central heating system, minimum COP for heat pumps etc.; when these are applied, it is assumed that the overall system efficiency is sufficient.
- System performance only exists on a building level (in order to calculate the energy performance indicators for the energy performance certificates (EPC); TBS must have a certain minimum quality to meet the whole building requirement.

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[10] CA EPBD, 2015, p. 32

- Requirements only apply to a fraction of the building stocks, partly single family homes or non-residential buildings are excluded.
- There are only vague or no requirements for installation, dimensioning, adjustment and control: "the designer needs to care about it".
- Difficult calculations exist, but are not commonly applied in practice.
- "System" is mixed up with components
- Partly there are "recommendations" rather than requirements.

Although the above cited provisions of the EPBD certainly could be more precise, the extent to which they are *not* followed, is striking. Re-arranging above mentioned items leads to the following bundles that offer quite some room for improvement:

- *All types* of systems mentioned in article 8 should be included in the requirements (heating, domestic hot water etc.) – for all types of buildings.
- *All functions* of e.g. heating systems, i.e. generation, distribution, emission and control should be covered.
- *All aspects* mentioned in article 8 should be addressed within the requirements, i.e. the *overall* energy performance of the technical building system, proper installation, appropriate dimensioning, adjustment and control.
- *All cases* where the system requirements need to be applied must be included and clearly mentioned: the renewal, replacement and upgrade of technical building systems in all existing buildings - not just in buildings that undergo major renovation.

Apart from that dedicated national incentive programs may accelerate the uptake of optimisation of TBS. For example, the German program for optimisation of heating systems ("Heizungsoptimierung") which was introduced in August 2016 is well received and used. It provides non-repayable grants up to 30% for purchase and/or professional installation/setting of e.g. individual room controls, balancing valves, monitoring & control devices and adjustment of the heating curve.

2.3 What hinders the implementation of Article 8?

The individual country reports of the Concerted Action EPBD in fact do not elaborate a lot on the reasons for the significant implementation gap of Article 8 on a country level. There are rather a few hints between the lines that we also heard in our expert interviews:

- There seems to be a serious lack of awareness that performance requirements mentioned in Article 8 need to be applied <u>whenever</u> TBS in <u>existing</u> buildings are newly installed, replaced or upgraded. Article 8 does not mention any minimum threshold to be fulfilled for this requirement. The only threshold mentioned is that requirements only "*shall be applied in so far as they are technically, economically and functionally feasible"*. Yet there was no reporting at all about the rules which apply to decide about these criteria.
- A specific challenge seems to be the implementation of the "system requirement for the overall energy performance". It seems that many countries see it as too complicated to set up such requirements. This specifically goes for existing buildings, where as a default a lack

of TBS documentation can be assumed. This seems to make it hard to determine overall systems performance. It also seems to be seen as an inadequately high effort to determine and comply with overall systems performance when just single components are replaced. If in these cases it would turn out that the overall system does not meet the overall performance requirements, also other elements of the TBS would need to be improved. Yet, we understand this is exactly the intention of Article 8 EPBD. The most economical moment to check and improve the overall TBS performance happens when the installer is on site due to failure or renewal of an individual component.

- We also interpret a significant confusion about the term "system". In CA EPBD country reports we could find that system requirements are in place, but in several cases boiler efficiencies, i.e. component/product efficiencies were immediately given as an example. On the other hand the EPBD certainly intentionally asks for system requirements rather than for product or component requirements as component requirements alone still might not lead to an adequate system performance. The idea of a system requirement is that for example a combination of single components of a heating system, that each fulfil a component requirement, are also adjusted to each other and hence the performance of the whole system fulfils the requirement – which often means a significantly higher efficiency than just optimizing each product separately. For example a heating system pipework may be designed with unnecessary long pipe lengths[11] - however properly insulated. While the pipework by itself would be in line with the requirement regarding the insulation of pipes, the inefficiency would then be "detected" by an overall energy performance indicator.
- In none of the reports we could find a real attempt to define system requirements for a *combination* of systems.
  Several countries mention several types of regulations or recommendations that already had been in place before the EPBD came into force. In some cases it is explicitly stated that even those are not really applied in practice. It seems that countries do not dare to add more requirements to a set of already existing, but scattered requirements and recommendations as they may have doubts about the actual impact. Sometimes we feel that "technical and economical feasibility" may be put forward as a welcome reason to not be forced to solve this dilemma, which we acknowledge is certainly not an easy one to solve in many cases.

2.4 Potential way forward

In general there is no uniform approach across the MS but scattered requirements on component level and various attempts on the level of individual systems. Building automation, which has the potential to optimise this interaction, is addressed even less. Obviously, there is a severe lack of guidance on how to interpret and implement Art. 8.

The next chapter analyses the effects of optimisation measures for technical building systems and packages composed of these measures for eight reference cases in order to determine the saving

[11] E.g. the DIN V 18599 algorithms calculate with unnecessary long pipe lengths

potential a consequent optimisation could have. Afterwards we will draw conclusions and recommendations also included the state of play analysed in the previous chapters.

3 Effects of optimisation packages on reference case level

The aim of this task is to analyse the savings that can be achieved by optimisation of existing building systems in different types of buildings. For this purpose, we determine the savings potential from optimisation measures for eight different reference cases. As we intend to investigate the potential that can be exploited by fully implementing Article 8, we bundle several single optimisation measures into two different packages: a) *Get the basics right*-package and b) *High performance*-package. While the *Get the basics right*-package bundles quick-win, "no-regret" measures (e.g. thermostatic radiator valves – TRV, automatic hydronic balancing), the *High performance*-package mainly adds more advanced building automation and control measures to it.,

The output of this task are eight factsheets (see annex) containing information about the specific reference case (base case) and the saving potential for the packages improving the building systems' performance and thus, the whole building's energy performance, with a focus on optimising the technical building systems.

3.1 Methodology

In a first step, eight reference buildings with their respective heating, cooling, hot water, ventilation and lighting specifications are defined. Then, optimisation measures and packages regarding the aspects mentioned within Article 8 of the EPBD (appropriate dimensioning, proper installation, adjustments and automation, control and monitoring systems) are developed (step 2) followed by norm conform calculations of their saving potentials (step 3). Figure 1 illustrates the general approach.

In order to ensure that the calculated savings can be attributed to the optimization of the technical building system (TBS) independent of the heat generator, the saving potential of each improvement measure is calculated per case assuming that the building *already has* a new high efficient heat generator. Therefore, all *additional* savings beyond Business-As-Usual shown in this study **do not include** any savings linked to a mere replacement of the heat generator. The reason is that the efficiency of heat generators (being a product) is regulated under the Ecodesign Directive. Due to that we assume old heat generators to be replaced by efficient ones meeting Ecodesign requirements at an annual rate of 3.6% as a baseline until 2030. Starting from that baseline we focus on the *additional* savings from *optimisation* of the interplay of products making up the technical building *system,* which *should be achieved by proper national implementation* of Article 8 EPBD in case these are renewed, replaced or upgraded.

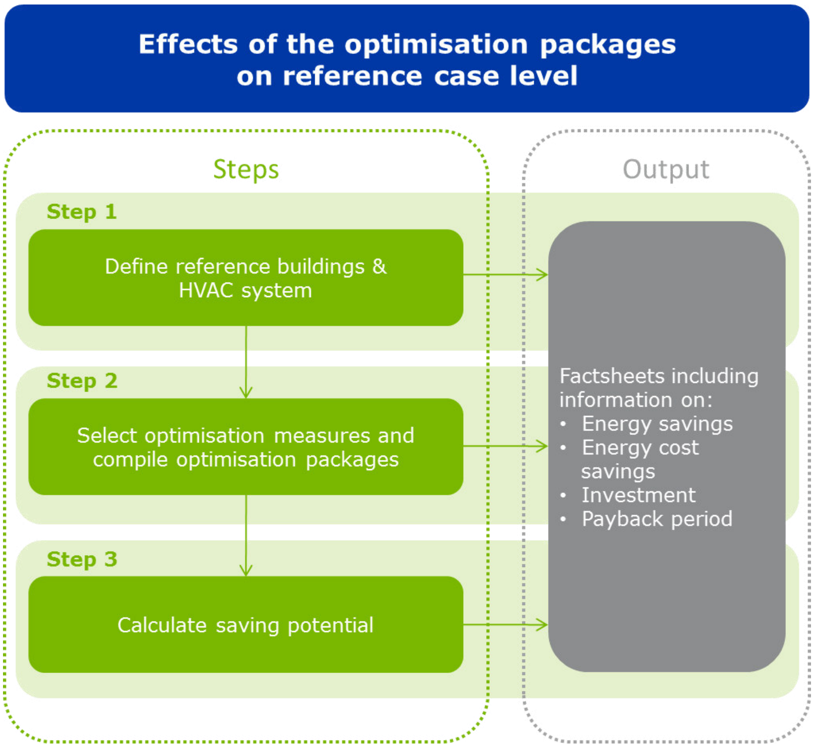

Figure 1: Approach for calculating the savings potential of optimisation measures and packages for the reference cases

3.1.1 Step 1: Definition of reference buildings & HVAC system

The analysis is conducted on a reference building level. A reference building is a typical building of its building stock[12]. This allows us to analyse the entire EU28 building stock by conducting bottom-up analyses, on different reference buildings. Typical residential reference buildings are e.g. detached or semi-detached single and multi-family houses of different sizes and/or age classes (construction phases). Typical non-residential (commercial) building types are e.g. office buildings, schools, hotels, hospitals, and retail facilities. For this project, we will use a semi-detached single-family house, an attached multi-family house, an office building and a supermarket.

The following eight reference cases are being analysed:

[12] Building stock: A building stock represents the entirety of buildings e.g. within a country. For example, the EU28 building stock represents all buildings in the EU28 Member States.

Table 2: Overview of the eight reference cases

Reference building	HVAC system
Single-family house	Gas heating with radiators
Multi-family house	Central gas boiler with radiators
	District heating with radiators
	Central heat pump with radiators
Office buildings	Radiators (heating)
	Air conditioning (heating and cooling)
Supermarkets	Standard supermarket
	Advanced system with heat recovery from refrigeration system

The reference cases correspond to a typical situation of the European building stock. We select the German building stock as it can be considered a good proxy for a building stock situated in a moderate climate zone. We consider the German climate as a proxy for the average European climate as the German heating degree days match the EU28 average very well[13]. Although the German climate can be used as average European climate, within the definition of the reference cases (buildings), non-German situations are considered (e.g. modified quality of thermostatic valves) with the intent to make the results valid beyond the scope of Germany. Specifically with a view to the extrapolation of reference case savings to the EU level, care was taken to make assumptions that avoid overestimation of absolute savings triggered by optimization of TBS. For the parameter determination of the reference cases, concrete choices must be made (such as u-values, climate data, energy prices, investment cost, etc.); with those choices reflecting the state in Germany. This is the starting point for the extrapolation to EU level in chapter 4.

For the analysis, it is crucial to use typical construction characteristics of the considered building types, e.g. size, geometries, insulation level by regulation, typical HVAC equipment (space heating system etc.), window types and sizes, orientation etc. For a sound basis, we relied on the following main sources:

- Offermann, Markus; Manteuffel, Bernhard von; Hermelink, Andreas (2013): Begleituntersuchung zur europäischen Berichterstattung "Cost-Optimal-Level" – Modellrechnungen, Edited by Bundesministerium für Verkehr, Bau und Stadtentwicklung (BMVBS). ECOFYS (BMVBS-Online publication, 26/2013). [Offermann et al., 2013]
- Institut für Wohnen und Umwelt (IWU) (2012): TABULA project (Typology Approach for Building Stock Energy Assessment) [IWU, 2012]

[13] Eurostat, 2015 (HDD_{DE} = 2908; HDD_{EU28} = 2904)

- Loga, Tobias; Diefenbach, Nikolaus; Born, Rolf (2012): Deutsche Gebäudetypologie - Beispielhafte Maßnahmen zur Verbesserung der Energieeffizienz von typischen Wohngebäuden (elaborated withjn the EU project „Typology Approach for Building Stock Energy Assessment" - TABULA). Institut Wohnen und Umwelt. Germany. Edited by Institut für Wohnen und Umwelt (IWU) [Loga et al., 2012]
- Klauß, Swen; Kirchhof, Wiebke (2010): Entwicklung einer Datenbank mit Modellgebäuden für energiebezogene Untersuchungen, insbesondere der Wirtschaftlichkeit. Report by order of the German Federal Ministry of Transport, Building and Urban Development (BMVBS) and the German Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR). Edited by Zentrum für Umweltbewusstes Bauen e.V (ZUB). Kassel. [Klauß and Kirchhof, 2010]

3.1.2 Step 2: Selection of optimisation measures & compilation of optimisation packages

The measures that are analysed are measures that are addressed under Article 8 of the EPBD in the following four categories:

- Appropriate dimensioning (e.g. space heating and hot water circulation pumps)
- Proper installation (e.g. insulation levels of the space heating and hot water pipework)
- Adjustment (e.g. night setbacks for space heating and hot water, manual hydronic balancing)
- Automation, control and monitoring systems (e.g. active control/building automation and installation of modern thermostatic valves)

The single optimisation measures are described in the annex.

In a next step, we will bundle several single optimisation measures into two packages:

1. *Get the basics right*
2. *High performance* (including *Get the basics right*)

The "Get the basics right" packages will include basic measures with low investment and short payback period. The *High performance* packages will include the measures of the *Get the basics right*-packages and furthermore a set of more advanced measures (mainly building automation and control systems) leading to an ambitious compilation.

These packages are applied to the reference buildings that will be described in 3.2.1 and 3.3.1. In the composition of the packages, overlapping effects of single measures are taken into account, e.g. manual and automatic hydronic balancing cannot be added up. Practically, the packages need to be defined for each reference building.

The optimisation packages per reference case will be described in the chapters 3.2.2 and 3.3.2.

3.1.3 Step 3: Calculation methodology for the saving potential

We calculated the energy demand (space heating, ventilation, hot water, lighting and cooling energy demand) for each reference case and every measure and took into account national climate data and normative reference calculation parameters according to EN 15232 and 15316 for the EPBD aspect *automation, control and monitoring systems* and DIN V 18599 for the aspects *appropriate dimensioning, proper installation*, *adjustment*. The DIN V 18599 was chosen because a CEN-EPBD conformity was ensured[14]. The following paragraphs outline brief introductions to the European and German norms used in this study.

<u>Saving potential according to DIN V 18599[15]</u>

The DIN V 18599 provides a method for assessing the overall energy efficiency of buildings as required by all Member States of the European Union (EU) by 2006 in accordance with Article 3 of Directive 2002/91/EC of the European Parliament and of the Council on the overall efficiency of buildings (EPBD). Calculations according to DIN V 18599 permit the assessment of all energy quantities necessary for heating, cooling, water heating, air-conditioning and lighting of buildings.

In doing so, the standard also takes account of the mutual influence of energy flows from the building and building systems. The algorithms of DIN V 18599 are designed for the energy balance of residential and non-residential buildings as well as of new and existing buildings.

The DIN V 18599 has been designed in such a way that the European standards, commissioned by the European Commission in the context of the implementation of the EPBD, have already been taken into account. With the DIN V 18599 a CEN-EPBD conformity was ensured which is not the case for the majority of standards that are used in other EU Member States[16]. Only in Luxembourg and Germany the recommended "holistic approach" is incorporated in the national calculation methodology with which the interaction between building and building systems is considered. Additionally, in the European context, the DIN V 18599 covers the greatest variance of innovative technologies[17].

For the reason mentioned above, the DIN V 18599 has been chosen in this investigation by applying the highly-regarded and certified software "Hottgenroth Energieberater 18599" to calculate the energy savings according to DIN V 18599. The DIN V 18599 applies a static simulation on a monthly basis[18] with the following main boundary conditions for residential buildings[19]:

- Required indoor temperature
    - Heating: 20 °C
- Cooling: 25 °CInternal heat gains
    - SFH: 45 Wh/(m².d)
    - MFH: 90 Wh/(m².d)

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[14] DIN, 2013
[15] DIN, 2013
[16] CENSE, 2010
[17] ASIEPI, 2010 e.g. demand-driven ventilation, daylight sensors, gas heat pump, etc.
[18] Note: Also software for hourly simulations exist, but is not widespread under practitioners.
[19] The boundary conditions for non-residential buildings differ per zone.

- Utilization time: 365 days, 24 hours
- Operating time ventilation: 24 hours
- Operating time heating: 17 hours

The DIN V 18599 includes the following gains/losses in the determination of the space heating demand: transmission, ventilation, solar gains, internal gains/losses.

Saving potential according to EN 15232 / EN 15316

The EN 15232: 2012 *Energy performance of buildings. Impact of Building Automation, Controls and Building Management* standard provides a methodology for assessing the impact of different BACS solutions on the energy performance of buildings. The methodology maps the BACS technological solution applied to the corresponding technical building energy system (heating, lighting, cooling, ventilation, hot water) and allows the determination of energy impacts. Two methodologies are permitted – one is a very detailed approach whose methodology varies significantly depending on the technical building system considered and that draws upon derivative calculations made in other EN standards that address each one of the technical building systems. The other is the so called "BACS factor" method that assigns performance classes (D, C, B or A) to the BACS solution. It indicates corresponding energy performance multiplier factors to be applied to the energy consumption of each technical building system as a function of the BACS class chosen and the type of building considered. These factors are derived in the standard from averaging the outcomes of a great many TRNSYS[20] simulations of European buildings and BACS combinations. In this report, we generally apply the BACS factor methodology to derive the impact of different BACS choices for all BACS types considered and all buildings.

The impact of hydronic balancing solutions is estimated in line with the methodology provided in EN 15316-2:2007 *Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating emission systems* for both emitters and pumping energy. We have used the methodology within this standard to be consistent with agreed EU methodologies.

As described above, the calculated savings are based on national and European standards and can differ in reality as they are sensitive to the behaviour of the end-user (e.g. when implementing new radiator valves the savings highly depend on the ventilation behaviour of the end-user, see [Hirschberg, 2016][21].

[20] TRNSYS (Transient System Simulation Tool) is a simulation program which is able to perform dynamic simulations on an hourly basis.

[21] The full study is available upon request from either Ecofys or Danfoss A/S.

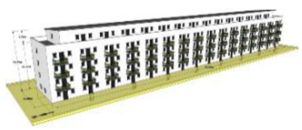
3.2 Residential buildings

3.2.1 Reference buildings and HVAC system

As mentioned before, we define reference buildings for Germany according to the sources mentioned in chapter 3.1.1, and in some cases slightly modify them to be representative for the moderate European climate zone.

The following table gives an overview of the chosen residential reference buildings and their specifications:

Table 3: Residential reference buildings[22]

<table>
<tr><th colspan="2">Reference buildings</th><th>External building component</th><th>Area [23] [m²]</th><th>U-Value [W/m²K]</th><th>Thermal bridge [W/m²K]</th><th>A/V [24] [m⁻¹]</th><th>Floor area [m²]</th><th>Share of window area[25] [%]</th></tr>
<tr><td rowspan="7">Semi-detached house</td><td rowspan="7">
View Southeast</td><td>Facade north</td><td>0</td><td rowspan="4">0.34</td><td rowspan="7">0.1</td><td rowspan="7">0.52</td><td rowspan="7">165</td><td rowspan="7">9</td></tr>
<tr><td>Facade west</td><td>30</td></tr>
<tr><td>Facade south</td><td>71</td></tr>
<tr><td>Facade east</td><td>30</td></tr>
<tr><td>Roof / upper floor ceiling</td><td>100</td><td>0.25</td></tr>
<tr><td>Ground plate</td><td>86</td><td>0.52</td></tr>
<tr><td>Windows</td><td>22</td><td>1.3</td></tr>
<tr><td rowspan="7">Multi-family house</td><td rowspan="7">
View Southeast</td><td>Facade north</td><td>146</td><td rowspan="4">0.34</td><td rowspan="7">0.1</td><td rowspan="7">0.44</td><td rowspan="7">3,811</td><td rowspan="7">14</td></tr>
<tr><td>Facade west</td><td>1,232</td></tr>
<tr><td>Facade south</td><td>146</td></tr>
<tr><td>Facade east</td><td>1,232</td></tr>
<tr><td>Roof / upper floor ceiling</td><td>1,001</td><td>0.25</td></tr>
<tr><td>Ground plate</td><td>1,001</td><td>0.52</td></tr>
<tr><td>Windows</td><td>522</td><td>1.3</td></tr>
</table>

The reference cases represent a partly refurbished building, i.e. the insulation of roofs and walls have been improved to a moderate level, and modern double-glazed windows have been installed. No improvements of the ground plate have been implemented. As to technical building systems, new heat generators are assumed as a starting point for the subsequent optimisation of technical building

[22] The reference buildings and its geometries are based on [ZUB 2010], [IWU 2012] and [BBSR 2013]
[23] The area comprehends facade areas including windows.
[24] Ratio of surface (A) to volume (V) to illustrate compactness of a building.
[25] Share of area referring to external building component area.

systems. We analyse one case for the single-family house and three different cases for the multi-family house:

- Single-family house:
  - Gas boiler[26] with radiators, hot water by heating system and without circulation system, no space cooling, natural ventilation
- Multi-family house:
  - Central gas boiler[27] with radiators, hot water by heating system and with circulation system, no space cooling, natural ventilation
  - District heating[28] with radiators, hot water by heating system and with circulation system, no space cooling, natural ventilation
  - Central heat pump[29] (air to water) with radiators, hot water by heating system and with circulation system, no space cooling, natural ventilation

The technical building systems of the residential case studies are illustrated in the following tables.

[26] For residential buildings a focus is set on gas boilers because they cover more than 40% of the residential space heating consumption of the EU28 building stock (with a heating system exchange rate of about 3.6% per year at EU level, gas fired heating systems will still remain the norm in the near future).
[27] See comment above.
[28] District heating covers appr. 10% of the residential space heating consumption of the EU28 building stock (and the share is likely to increase by 2050).
[29] Also a heat pump option is investigated (with minimum renovation works needed, i.e. while keeping the existing water based heating system) as heat pumps are likely to become a very important heating system in the future.

Table 4: Summary of the assumed HVAC system configuration for the reference single-family building

	Parameter	Reference value
HVAC	Valve	Thermostatic radiator valve (TRV) before 1988[30][31]
	Type of radiator	Ripped radiator
	Design supply / return temperature	70/50 (but only 55/45 required)
	Pipe system	2 pipe
	Heating curve	Default settings (no individual adjustments)
	Night setback (lower temperature at night)	No
	Insulation of pipes	All pipes moderately insulated (U-value: 0,4 W/(m²K) ~30-40% of pipe diameter)
	Pump	Pump, on/off, over dimensioned (100 %) and not adjusted
	Boiler / heat pump	New boiler/ new heat pump
	Control system	Poor control and settings => Control of heat emitters provided by central automatic control (scheduler based on a single thermostat); no sensing of ambient temperature or associated control, no automatic control of distribution network hot water temperature (supply or return); on/off control of distribution pumps
	Hydronic balancing	Systems are not balanced
Hot water	Circulation system	No
	Insulation of pipes	All pipes moderately insulated (U-value: 0,4 W/(m²K) ~30-40% of pipe diameter)
	Hot water storage tank	Yes, in non-heated area
	Legionella protection	No (50 °C, System temperature)

[30] According to ECOFYS, 2016a, about 47% of the installed valves in Europe are manual valves [see footnote 31]. Yet a large share of these valves is allocated in countries with less heating degree days and thus less space heat consumption and less absolute space heat savings potential like Italy and Spain. In Germany the share of manual radiator valves is only 6% and comparatively new self-acting thermostatic radiator valves with a relatively precise control dominate. A compromise had to be found to make the German building representative for the European average situation. Therefore we assumed the reference building to be equipped with 30 years old self-acting thermostatic radiator valves (TRV), which has a relatively imprecise control ("2 K") of the room temperature.

[31] Manual radiator valves are radiator valves where water flow into the radiator depends on a manual flow setting only. This means the end user regularly would need to adjust the setting of the radiator valve in order to achieve a certain temperature and a comfortable indoor climate. A self-acting or an electronic thermostatic radiator valve (TRV), however, adjusts the water flow into the radiator in dependence of ambient temperature selected by the end user. It is able to ensure a comfortable indoor climate keeping the desired temperature automatically without regular manual adjustments.

Table 5: Summary of technical building system for the reference multi-family building

	Parameter	Reference value		
		Central gas boiler with radiators	District heating with radiators	Central heat pump (air to water) with radiators
HVAC	Valve	See table for single-family building		
	Type of radiator			
	Design supply / return temperature			
	Pipe system			
	Heating curve			
	Night setback			
	Insulation of pipes			
	Pump			
	Boiler / heat pump			
	Control system	Poor control and settings = Control of heat emitters provided by central automatic control (scheduler based on a single thermostat); no automatic control of distribution network hot water temperature (supply or return)		
	Hydronic balancing	Systems are not balanced		
Hot water	Circulation system	Yes (24/7) circulation pump over dimensioned (100 %) and not adjusted		
	Insulation of pipes	All pipes moderately insulated (U-value: 0,4 W/(m²K) ~30-40% of pipe diameter)		
	Hot water storage	Yes, in heated area		
	Legionella protection	Yes (65 °C system temperature)		

3.2.2 Optimisation packages

As outlined in 3.1.2 the analysed measures are addressed under Article 8 of the EPBD in the following four categories: *appropriate dimensioning*, *proper installation*, *adjustments and automation*, *control and monitoring systems*. The single optimisation measures are described in the annex.

In this step, we bundle several single optimisation measures into two packages:

1. *Get the basics right*
2. *High performance* (including *Get the basics right*)

These packages are applied to the reference buildings that have been defined in the previous chapter. As outlined in 3.1.2 overlapping effects of single measures are taken into account in the composition of the packages.

Get the basics right optimisation package:

In the *Get the basics right* packages for residential buildings we include measures regarding *appropriate dimensioning* (of space heating and hot water circulation pumps), *proper installation* (concerning a higher insulation level of the space heating and hot water pipework) *system adjustments* (such as night setbacks[32] for space heating and hot water, automatic hydronic balancing[33] and installation of modern thermostatic valves). *Automation* and *control and monitoring systems* are not included in the package.

High performance optimisation package:

In the *High performance*-packages for residential buildings we include measures of the *Get the basics right*-package regarding *appropriate dimensioning*, *proper installation* (with even better insulation levels) and system adjustments. Advanced *Automation* and *control and monitoring systems* are included in the package (e.g. measures concerning boiler and pump optimisation and the installation of electronic thermostatic radiator valves are included).

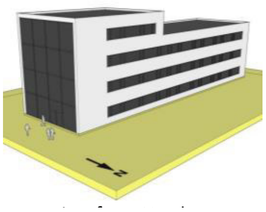
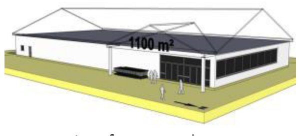
A detailed compilation of the packages is presented in the annex.

[32] Adjusted settings (from 11pm to 6am, 2K temperature reduction)
[33] Continuous control of flow and pressure in the piping system and radiators leading to an optimised generation, distribution and emission of heat throughout the building.

3.3 Non-residential buildings

3.3.1 Reference buildings and HVAC system

Table 6 Reference buildings for the non-residential case studies[34]

Reference buildings		External building component	Area[35] [m²]	U-Value [W/(m²K)] [36]	Ther-mal bridge (W/m² K)	A/V [37] [m-1]	Refe-rence surface [m²]	Share of win-dow area [38] [%]
Office building	 View Northeast	Facade north	576	0.60	0.1	0.37	1,676	22
		Facade west	187					
		Facade south	598					
		Facade east	234					
		Roof / upper floor ceiling	591	0.40				
		Ground plate	591	0.60				
		Windows	611	1.3				
Supermarket	 View Northeast	Facade north	103	0.50	0.1	0.59	1,025	2
		Facade west	207					
		Facade south	103					
		Facade east	207					
		Roof / upper floor ceiling	1,152	0.30				
		Ground plate	1,152	0.60				
		Windows	70	1.3				

The reference cases represent a partly refurbished building. We analyse two different cases for each office building and supermarket reference:

1. Office building with:
   a. Radiators (space heating), fan coils (space cooling), mechanical ventilation without heat recovery
   b. Air conditioning system (space heating and space cooling), mechanical ventilation without heat recovery
2. Supermarket[39]:
   a. Standard supermarket with fan coil units (heating and cooling), mechanical ventilation without heat recovery (but preconditions the incoming air); this supermarket represents a typical inefficient supermarket; in the extrapolation
   b. Advanced supermarket with heat recovery from refrigeration system with fan coil units (heating and cooling), mechanical ventilation without heat recovery (but preconditions the incoming air).

Remark:

Heat recovery from commercial refrigeration systems has gained an increased interest during the last years. The principle of heat recovery is old but a systematic approach to utilize both the high and the low temperature sides of the gas compression system has rarely been seen until recently. Especially with the entrance of CO_2 as refrigerant, new ways of improving efficiency and cost are becoming evident [Funder-Kristensen et al., 2013]. Cooling technology in supermarket applications is of great energetic and economic importance. In Germany about 1.4% of the electricity consumption is used for refrigeration in supermarket application [Arnemann, 2014]. The refrigeration system has a significant impact on the final energy consumption within a supermarket. This is not considered as part of the technical buildings system. As the impact of a refrigeration system with heat recovery for space heating and hot water are significant, two different cases for supermarkets are chosen: the standard supermarket without heat recovery and the advanced supermarket using a refrigeration system with heat recovery. The advanced supermarket utilizes the surplus heat from the CO_2 refrigeration units to heat the space and domestic hot water within the same building. Thus its energy demand and energy cost are significantly lower than in the standard supermarket (compare factsheets for super-markets and Table 9).

The technical building systems of the non-residential reference buildings are illustrated in the following tables:

---

[34] The reference buildings and its geometries are based on [ZUB 2010], [IWU 2012] and [BBSR 2013].
[35] The area comprehends facade areas including windows.
[36] U-values reflect a conventional thermal modernisation of the building
[37] Ratio of surface (A) to volume (V) to illustrate compactness of a building.
[38] Share of area referring to external building component area.
[39] As to the extrapolation of results to the EU level (chapter 4) the advanced supermarket represents retail buildings, while the standard supermarket is assigned to represent only a very small share of 1% within the building stock.

Table 7: Summary of technical building systems for the office reference cases (Built: 1984-1994)

Parameter	Value	
	Office with radiators heating	**Office with air heating**
Setback during non-operating times	Yes (2 K)	
Design supply/return temperature (heating)	70/55 (but only 55/45 required)	
Hydronic control	On Off 3 way valves on fan coils and thermostatic radiator valves (TRV) before 1988 on radiators	
Hydronic balancing	Systems are not balanced	
Electronic control	Default settings (no individual adjustments) of heating curve	
Insulation of pipes	All pipes moderately insulated (U-value: 0.4 W/(m²K) ~30-40% of pipe diameter)	
Pump (space heating)	Pumps, on/off, over dimensioned (100%) and not adjusted	
Transmission	Radiators (heating) and fan coils (cooling, offices and conference rooms)	Air heating and cooling preconditioning (mechanical ventilation) combined with fan coil units (heating and cooling, in all zones)
Hot water	Decentral, instantaneous water heater[40]	
Mechanical ventilation	Constant airflow central supply- and exhaust air system with air heating function combined with fan coil units (constant supply air temperature 18 °C; required volume 30% over dimensioned for all zones[41]; without heat recovery)	As besides but with air heating and cooling function
Space cooling system	Compression Chiller (Air cooled) over dimensioned (100%) System temperatures 6/12 Pipes insulated with 50% of pipe thickness Pumps, on/off, over dimensioned (100 %) and not adjusted Air temperature setting: 24 °C	Compression Chiller (Air cooled) over dimensioned (100%) System temperatures 6/12 Pipes insulated with 50% of pipe thickness Pumps, on/off, over dimensioned (100 %) and not adjusted Air temperature setting: 24 °C
Lighting	Direct/indirect fluorescent tubes (t5 => 12 W/m² in the offices and meeting rooms; 5 W/m² in the corridors and other rooms) manually controlled	

[40] According to BMWi, 2015 for retail, commercial, services in 2010 (heating supply): 31% natural gas, 25% oil, 23% electric (for office buildings, direct electric heaters were assumed due to reduced demand for warm water), 14% district heating, 7% renewable energy
[41] Air change rates (30% over dimensioned) for the zones are: office = 3.3 1/h; conference rooms and WC = 5.6 1/h; circulation space = 0 1/h; storage = 0.05 1/h

Parameter	Value	
Building automation and controls (incl. settings)	BEMS system in place but with many of the functions not used or disabled. Central activation of boiler in accordance to pre-programmed occupancy schedule. No weather compensation or optimum/start stop. Central automatic control of heat emitters by zone (which comprises all rooms which get the same supply water temperature). Typically, this is via a supply water temperature control loop whose set-point is dependent on the filtered outside temperature, e.g. the average of the previous 24 hours. No automatic control of distribution network hot water or cold water temperature (supply or return). On/off control of control valves and distribution pumps. Lighting with manual on/off switching but mostly by zones. Automated night-time deactivation.	BEMS system in place but with many of the functions not used or disabled. Central activation of boiler in accordance to pre-programmed occupancy schedule. No weather compensation or optimum/start stop. Central automatic control of heat emitters by zone (which comprises all rooms which get the same supply water temperature). No automatic control of distribution network hot water and cold water temperature (supply or return). On/off control of control valves and distribution pumps. Time controlled air flow of cold emitters by zone. Air handler on off time control: Continuously supplies of air flow for a maximum load of all rooms during nominal occupancy time. No interlocks to prevent simultaneous heating and cooling. Lighting with manual on/off switching but mostly by zones. Automated night-time deactivation.

Table 8: Specifications of the technical building system in the two supermarket reference cases (built: 1995 onwards)

Parameter	Specifications	
	Supermarket standard	**Supermarket advanced** **– with heat recovery from refrigeration system**
Space heating system	Gas-condensing boiler over dimensioned (50%)	As besides but with use of refrigeration system excess heat
Setback during non-operating times	Yes (2 K)	
Design supply/return temperature (heating	70/55 (but only 55/45 required)	
Heating curve	Default settings (no individual adjustments)	
Insulation of pipes	All pipes moderately insulated (U-value: 0.4 W/(m²K) ~30-40% of pipe diameter)	
Pump (space heating)	Pumps, on/off, over dimensioned (100%) and not adjusted	
Transmission	Air heating and cooling preconditioning (mechanical ventilation) combined with fan coil units (heating and cooling)	

Parameter	Specifications	
Mechanical ventilation	Constant airflow central supply- and exhaust air system with air heating and cooling function combined with fan coil units (constant supply air temperature 18 °C; required volume 30% over dimensioned for all zones[42]; without heat recovery)	See central column
Space cooling system	Fix speed compression Chiller (Air cooled) with mech. expansion, refrigerant: HFC, 100% over dimensioned Fan coil units System temperatures 6/12 Pipes insulated with 50% of pipe thickness Pumps, on/off, over dimensioned (100%) and not adjusted; Air temperature setting: 24 °C	See central column generation by central staged compression chiller (Air cooled) for refrigeration and air conditioning; with electr. expansion valve, 100% over dimensioned; refrigerant: CO_2
Lighting	Direct/indirect fluorescent tubes (t5 => 10 W/m^2) manually switched on during the operating times	
Building automation and controls (incl. settings)	BEMS system in place but with many of the functions not used or disabled. Central activation of boiler in accordance to pre-programmed occupancy schedule. No weather compensation or optimum/start stop. Central automatic control of heat emitters by zone (which comprises all spaces which get the same supply water temperature). No automatic control of distribution network hot water and cold water temperature (supply or return). On/off control of control valves and distribution pumps. Time controlled air flow of cold emitters by zone. Air handler on off time control: Continuously supplies of air flow for a maximum load of all zones during nominal occupancy time. No interlocks to prevent simultaneous heating and cooling. Lighting with manual on/off switching but mostly by zones. Automated night-time deactivation	

[42] Air change rates (30% over dimensioned) for the zones are: retail = 1.4 1/h; storage = 0.05 1/h; recreation room = 2.4 1/h; small kitchen = 5.1 1/h

3.3.2 Optimisation packages

As outlined in 3.1.2, the measures that are analysed are addressed under Article 8 of the EPBD in the following four categories: *Appropriate dimensioning*, *proper installation*, *adjustments* and *automation*, *control and monitoring systems*. The single optimisation measures are described in the annex.

In this step, we bundle several single optimisation measures into two packages:

1. ***Get the basics right***
2. ***High performance* (including *Get the basics right*)**

These packages are applied to the reference buildings that have been defined in the previous chapter. As outlined in 3.1.2, overlapping effects of single measures are taken into account in the composition of the packages, e.g. manual and automatic thermal balancing cannot be added up.

Get the basics right optimisation package:

In the *Get the basics right*-packages for non-residential buildings we include measures regarding *appropriate dimensioning* (of space heating and cooling pumps), *proper installation* (concerning a higher insulation level of the space heating and hot water pipework) *system adjustments* (such as air volume adjustment to actual demand). *Automation, control and monitoring systems* are not included in the package.

High performance optimisation package (advanced):

In the *High-performance*-packages for non-residential buildings we include measures of the *Get the basics right*-package regarding *appropriate dimensioning*, *proper installation* (with even better insulation levels) and *system adjustments*. *Automation*, *control and monitoring systems* are included in the package (e.g. measures concerning heating and cooling (such as control of emitters by individual room control), ventilation (such as room air temperature control) and lighting (such as occupancy and daylight control).

A detailed compilation of the packages is presented in the annex.

3.4 Results – Effects of the optimisation packages on reference case level

This chapter presents the results on package level and discusses them. We calculated the energy savings and payback periods per single optimisation measures (see annex). The majority of the single measures have a payback period of less than 5 years for all reference cases (e.g. thermostatic valves, boiler and pump adjustments, night setbacks or room air temperature control for ventilation and occupancy and daylight control for lighting).

Subsequently, we calculated the effect when single measures are applied in a package: as described before we assumed a G*et the basics right* and a *High performance* package. The packages are composed of a selection of single measures as described in the chapters before (the exact compilation of the packages can be found in the annex).

As we are aware there is a lot of discussion going on around the savings potential of thermostatic radiator valves (TRV), for this specific measure we'd like to highlight, how we handled it, also in comparison to other well-known studies. The aim is to create an adequate understanding of the savings that are calculated in the present study and how they compare to the results of other studies. The explanations given here for TRV may also be applicable to other measures investigated in this study, as differences between studies usually stem from different baselines, underlying assumptions and objectives.

Excursus self-acting thermostatic radiator valves (TRV)

We briefly discuss the difference between the EUnited valves study [ECOFYS, 2016a][43], the Hirschberg study [Hirschberg, 2016][44] and the present study. More information, including on electronic thermostatic radiator valves (eTRV) and a summary table of the main differences is presented in the annex (see Annex 2, chapter 6.2.2).

Regarding the EUnited valves study, the key difference of the two studies is that the EUnited Valves compares the potential energy savings if a *simple* manual radiator valve (SRV) is exchanged by a thermostatic radiator valve (TRV), plus additional hydronic balancing in 50% of the cases. The present study compares the exchange of a *thermostatic* radiator valve before 1988 (with rather imprecise 2 K control) with just installing standard thermostatic radiator valves, i.e. without additional savings from manual hydronic balancing. The selection of a TRV before 1988 as reference case is assumed to be a good proxy for the "EU average" radiator valve (see chapter 3.2.1).

Regarding the Hirschberg study the key difference is the calculation approach and the baseline. Hirschberg compares different operation modes and simulates the energy savings for different scenarios by using a dynamic thermal simulation software. The present study uses a normative approach based on reference buildings.

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[43] The full study is available upon request from either Ecofys or Danfoss A/S.
[44] The full study is available upon request from either Ecofys or Danfoss A/S.

Overview of the results

Most of the single measures (results, see annex) have a very short payback period. The payback period is mostly less than 5 years for all reference cases and for many measures (e.g. thermostatic valves, boiler and pump adjustments, night setbacks or room air temperature control for ventilation and occupancy and daylight control for lighting). The *packages* of the optimisation measures have a payback period of about 0.5 to 6 years (see Table 9). The saving potential of the optimisation packages are significant and – on the level of individual reference cases - are in a range from 14% to 49% with an average of about 30% savings of final energy. Some of the single measure are very easy to implement with very short payback period (e.g. exchange of the thermostatic valves, boiler and pump adjustments, night setbacks, etc.).

The following table is a summary of the results of the relative final energy savings compared to the "no optimisation" case, for each combination of packages and reference cases, including the energy costs savings, the investments and the payback period.

Table 9. Overview about optimisation packages

Reference building	Packages	Final energy savings [%]	Energy cost savings[45] [Euro]	Investment [Euro]	Payback period [years]
Single-family house	Get the basics right	21%	390	1,400	3.5
	High performance	33%	630	3,700	6.0
Multi-family house (Gas)	Get the basics right	28%	10,330	14,110	1.5
	High performance	40%	14,660	63,840	4.5
Multi-family house (District heating)	Get the basics right	29%	16,520	14,110	1.0
	High performance	40%	23,320	63,840	2.5
Multi-family house (Heat pump)	Get the basics right	34%	19,140	14,110	0.5
	High performance	46%	25,780	69,280	2.5
Office (Radiators)	Get the basics right	20%	7,970	7,150	1.0
	High performance	41%	18,560	78,350	4.0
Office (Air heating)	Get the basics right	18%	8,600	5,170	0.5
	High performance	44%	21,220	64,800	3.0
Supermarket (Standard)	Get the basics right	16%	10,610	4,910	0.5
	High performance	49%	30,700	35,360	1.0
Supermarket (Advanced)	Get the basics right	14%	2,370	4,910	2.0
	High performance	45%	8,080	36,110	4.5

[45] EU28 energy cost averages from 2017 to 2030 as used in EPBD impact assessment (Gas: 5.9 ct/kWh; District heat: 9.6 ct/kWh; Electricity: 21.9 ct/kWh)

In the next chapter, we extrapolate an estimated implementation of the optimisation package results for the reference case to the European building stock.

The focus on packages highlights the fact, that individual measures may imply different positive impacts in different parts of the system and also have synergies with other individual measures when being part of one package.

The biggest potentials for optimising building systems lie within the energy supply, distribution, transfer (mainly for heating but also for cooling) and in ventilation and lighting. We have summarised these TOP 5 items in the following excursus on the "Holistic approach for optimising technical building system".

Excursus: Holistic approach for optimising technical building systems

The results of the simulations show short payback times for single improvement measures. Within technical building systems a holistic approach of a well-tuned system is optimal to achieve the full potentials in line with Art. 8 EPBD.

We identified the following main pillars for energy efficient technical building systems.

- **Heat supply:**
  Dimensioning and control of the supply technologies according to the actual demand (e.g. by boiler settings concerning system temperatures and night setback)

- **Heat distribution:**
  Adapted heat distribution system with minimal heat losses to limit the system temperatures needed to serve the actual demand (e.g. hydronic balancing and appropriate insulation of pipework)

- **Heat transfer:**
  Control of indoor temperature to satisfy the actual demand (e.g. by thermostatic radiator valves)

- **Ventilation:**
  Reduce the ventilation rates to meet the actual demand (e.g. by reducing the overall ventilation rates and air quality control)

- **Lighting:**
  Control of the lighting system in commercial buildings (e.g. by occupancy and daylight control)

  Note 1: Although lighting is not explicitly mentioned within the technical building systems in EPBD Art. 8 we consider it still as relevant at least for the ambitious High performance packages in order to fulfill the scope of the EPBD outlined in Art. 2. This is because lighting is already part of the TBS definition in Article 2 EPBD (see introductory chapter on "Definitions", and lighting will be included the revised EPBD if the proposed Art. 8 remains unchanged.)
  Note 2: Ventilation and lighting are especially relevant in commercial buildings.

The measures within the different pillars (heat supply, distribution and transfer) affect each other. For example, the savings of a single measure like hydronic balancing allows to reduce the heating system temperatures which increases the efficiency of the condensing boiler by increased condensation effects. Additionally, also pump energy is saved and heat losses within the heat distribution system are reduced.

That is why in the present study the measures are reasonably combined to a *Get the basics right* and a *High performance* package.

4 Effects of optimisation packages on EU level until 2030

This chapter is to put the savings that can be achieved by optimising TBS into a European perspective, to underpin the urgency for action and to pave the way for our conclusions and policy recommendations in chapter 5. For this purpose we compare potential savings from the optimisation of TBS with the total savings that are to be achieved until 2030 by the proposed revision of the EPBD.

Therefore we first introduce into the magnitude of CO_2 reductions and primary energy savings which are to be achieved by the revised EPBD. Furthermore we provide insight into a more ambitious savings variant, that had been discussed during the impact assessment of the EPBD but finally was not chosen to be the preferred variant for implementation.

Then we estimate the order of magnitude of CO_2 emission reductions and primary energy savings that would result from aggregating the CO_2 reductions and primary energy savings we calculated for the optimisation of technical building systems of reference buildings to the EU level. Note that this is just what would follow from strictly implementing and enforcing Article 8 in the current EPBD.

Finally we compare the ambition for CO2 reductions and primary energy savings of the proposed revision with what would follow from fully exploiting the optimisation potential of TBS. to CO_2 reductions and primary energy savings that the proposed revision of the EPBD is to achieve.

4.1 CO_2 reductions and primary energy savings in the proposed revision of the EPBD

The objective of the EPBD is to promote the improvement of the energy performance of buildings within the EU, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. In the impact assessment the EPBD develops scenarios for different policy options, amongst others[46]:

- *No-change option* is a business as usual scenario and implies a continued implementation of the current EPBD and related regulatory and non-regulatory instruments and support measures such as sharing of good practices, stimulated by exchange platforms (e.g. Concerted Action). It does not include any additional EU measures as a result of a revised EPBD.
- *Option II (Enhanced implementation, including targeted amendments for strengthening of current provisions – the preferred option).* This option requires targeted amendments of the current EPBD to address the problem drivers more extensively. This option stays in line with the intervention logic of the current EPBD and addresses most drivers associated to market

[46] Impact assessment EPBD: COM (2016) 765 final}, {SWD(2016) 415 final}

failures. It develops a *smartness indicator* which has the aim to inform about the ability of buildings to operate smart (which means with increased efficiency, monitoring and controlling energy use and interacting with users and the grids. It also supports the development of infrastructure to support the roll-out of electro- mobility solutions. The implementation of this option would add 38 Mt CO_2 emission reductions and 30 Mtoe primary energy savings per year in 2030 compared to the *no change* option.

- *Option III (Enhanced implementation towards further harmonization and higher ambition).* This option addresses very ambitious measures in order to increase the renovation rate. Thus the resulting impact is very high. It foresees significant changes in the building sector, especially by introducing mandatory renovation of thousands of buildings (a measure which raises some issues such as obligatory investment amongst others. The implementation of this option would add 134 Mt CO_2 emission reductions and 74 Mtoe primary energy savings per year in 2030 compared to the *no change* option.

4.2 Methodology for determining optimisation package CO_2 reductions and primary energy savings on EU level

In this chapter scenarios for the CO_2 emission and primary energy mitigation effects on EU level in 2030, the investment costs and the energy cost savings are calculated. Additionally, assumptions are made about a Business-As-Usual scenario (BAU) – this is assumed to be equivalent to the *no change option of the* EPBD impact assessment. As we are interested in the *additional* CO_2 reductions and primary energy savings that can be achieved by optimisation of TBS, the overlap with the Business As Usual (BAU) scenario needs to be estimated. It would be unrealistic to assume that nothing from *Get the basics right* would be implemented in BAU. Finally, the scenarios are compared to each other and to the CO_2 reductions and primary energy savings of the proposed revision of the EPBD and a more ambitious path, that had been discussed during the EPBD impact assessment.

The extrapolation is done in various steps. The following figure illustrates this approach.

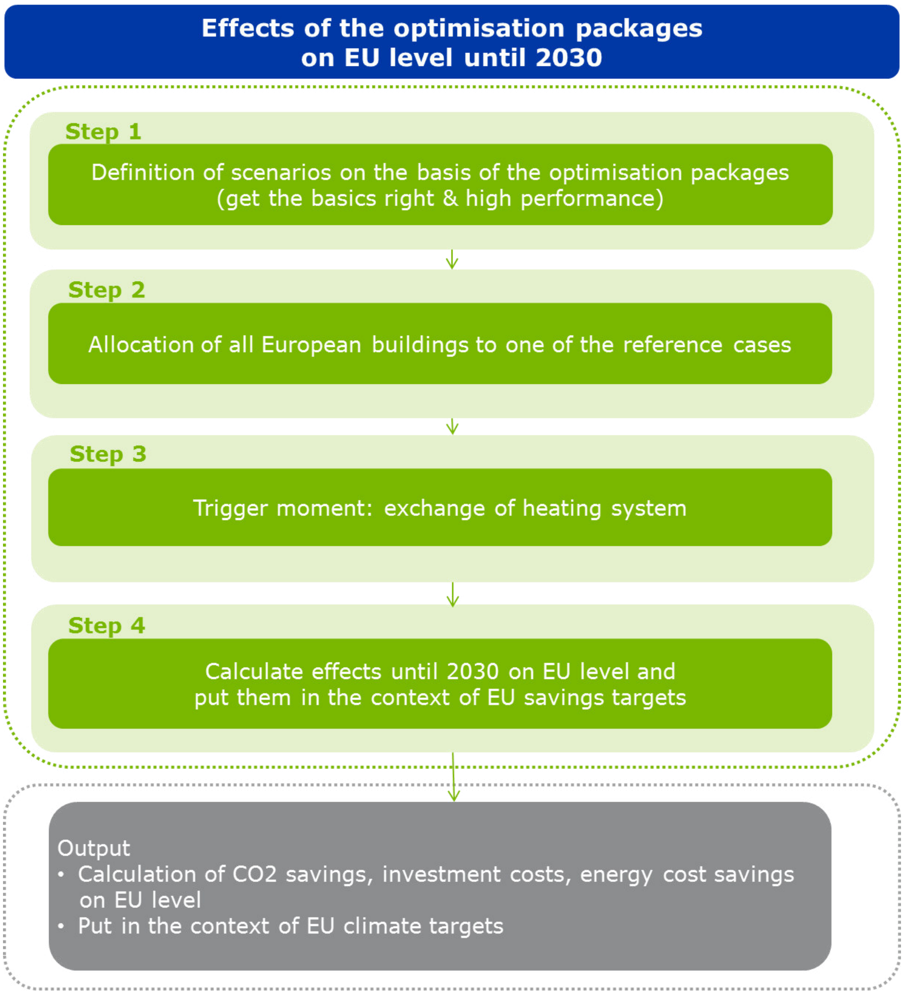

Figure 2: Approach to calculate the effects on EU level

<u>Step 1</u>

Based on the *Get the basics right* packages and the *High Performance* packages we developed two different scenarios: the G*et the basics right* scenario and the *High Performance* scenario (see 6.2.3). The scenarios are built based on robust assumptions regarding the implementation rate of these packages within the total European building stock, the share of the building stock that will be transformed by these packages, and the timeline for these changes.

<u>Step 2</u>

In this step, all buildings of the European building stock are allocated to one of the reference cases (see annex 1 for details). The study investigated 4 different reference buildings with different HVAC systems leading in total to eight different reference cases (see 3.2.1 and 3.3.1). The total building stock is allocated to these 8 reference cases. For details of the allocation, including an overview of the relative share within the building stock (residential and non-residential), see annex 1. The extrapolation is based on this distribution. The reference buildings that are used represent a simplified model of the European building stock. Simplifications are needed as an exact image of the building stock is not possible. Therefore, inaccuracies are unavoidable when a reference building does not match the buildings in the stock assigned to it. The reference cases correspond to a typical situation of the stock. We select the German building stock as it can be considered a good proxy for a building stock situated in a moderate climate zone. We consider the German climate as a proxy for the average European climate as the German heating degree days match the EU28 average very well [Eurostat, 2015][47] (see chapter 3.1.1).

Step 3

In this step the trigger moment for the implementation of a full optimisation package is defined: it is the exchange of the heat generator. This is an ideal moment for optimisation of technical building systems. There are measures that are more independent from the exchange of the heat generator than others. For instance, the exchange of the thermostatic radiator valve (TRV) can be considered relatively independent from the heat generator, whereas measures such as e.g. hydronic balancing or further system adjustments can be assumed to take place when the heat generator is exchanged.

Therefore, it was decided to set the implementation rate for optimisation of TBS equal to the EU average of the *exchange of heating systems* being about 3.6% (deduced from an expected life time of 28 years in [ECOFYS, 2016b]). The implementation rate of the single measures within the scenario packages may be higher or lower in reality, leading to higher or lower CO_2 reductions and primary energy savings respectively.

We assume that the most inefficient buildings will be the first where TBS will be optimised. Therefore the absolute savings potential of buildings to be renovated till 2030 is higher than what can be achieved in buildings after 2030. Within the 13 year period under consideration (mid 2017 till mid 2030) we assume that TBS may be optimised in 47% of all buildings, which equals 13 times 3.6%.[48].

Additionally, no technology switch in the heating systems was assumed over that period (e.g. from gas boiler to heat pump). Potentially lower primary energy and CO_2 reductions may result from a higher share of renewables in the future as a final energy reduction of a less environmentally friendly energy carrier has a higher impact.

Step 4

In order to roughly quantify what will happen in the BAU scenario between 2017 and 2030, the EPBD Impact Assessment not only provides good guidance but the most relevant BAU scenario for the purpose of this study. This BAU scenario assumes a *no change* option, where all the measures in place or already required for future implementation (like new nearly zero-energy buildings) will be continued or implemented, respectively. Yet, no further strengthening, no higher compliance, no additional legal measures etc. will occur till 2030. Thus, the implementation[49] of Article 8 is not improved either. In the *no change* option, savings of primary energy or CO_2 emission reductions will

[47] (HDD_{DE} = 2908; HDD_{EU28} = 2904)
[48] (2030-2017 = 13 years) * 3.6% implementation / year = appr. 47%
[49] CA EPBD, 2015

stem from a certain degree of implementing technical building systems, from exchange of boilers, upgrade of ventilation systems, window exchange, wall insulation etc., but also from decreasing primary energy and CO_2 factors, mainly for power and district heat. This means that, to a certain extent, BAU measures overlap with what we assume will happen in the *get the basics right* and *high performance* scenario.

Our assumptions regarding this effect are as follows:

- We assume that 1/3 of the reductions that we would get from implementing the Get the basics right packages with a rate of 3.6%/year would occur anyway in the BAU scenario.
- Moreover, some CO_2 reductions and primary energy savings will occur because CO_2 emission factors and primary energy factors will decrease from 2017-2030.
- For improvements of the building envelope, which also need to be considered in a BAU scenario, we assume a rate of 1.4%/ year. Between 2017 and 2030 this adds up to approx. 20% renovated buildings. We conservatively assume that by this alone real final energy consumption for heating will be reduced by 30% on average. Obviously, there will be a fraction of the building stock where until 2030 *Get the basics right and* improvements of the building envelope will occur. We assume this to happen in half of the buildings where we assumed improvements of the building envelope, i.e. in 10% of the building stock.

For plausibility reasons the performed bottom-up calculation has been calibrated top-down with EU28 energy consumption statistics. The results are presented in the following chapter.

4.3 Results – Effects of the optimisation packages on EU level until 2030 & contribution to EU targets

In this chapter we give an overview of the CO_2 reductions and primary energy savings that can be achieved through accelerated & advanced optimisation of technical building systems (TBS) starting with the least efficient buildings: proper installation, appropriate dimensioning, adjustment, control and automation.

Within the *Get the basics right* scenario mainly proper installation, appropriate dimensioning and adjustments (excluding advanced and connected building automation and control measures) are implemented within 47%[50] of the building stock. In those same buildings[51] the *High performance* scenario with a set of advanced measures (mainly advanced and connected building automation and control systems added on top of the *Get the basics right*-measures) are implemented. In order to consider that a part of the *Get the basics right* measures will be implemented anyway[52] the following figures also show *Business as usual* (BAU) savings.

[50] 3.6%/year from 2017 to 2030
[51] The same implementation rate is assumed.
[52] Expert assumption: One third of the *Get the basics right* savings due to legal and economic context.

The following figures show the additional emission reductions and primary energy savings in the two scenarios and the effect of the BAU savings that happen anyway including CO_2 reductions and primary energy savings due to ongoing decarbonisation of district heat and power and energy reduction assumptions[53] (see following figures).

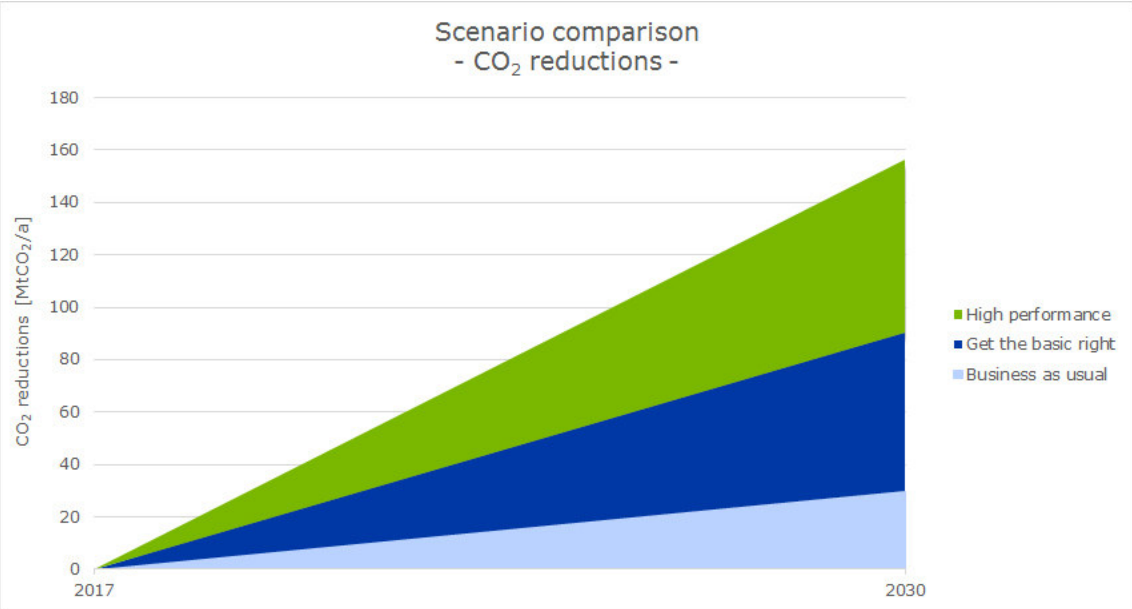

Figure 3: Scenario comparison, maximal potential reductions by TBS scenarios, Mt CO_2 per year

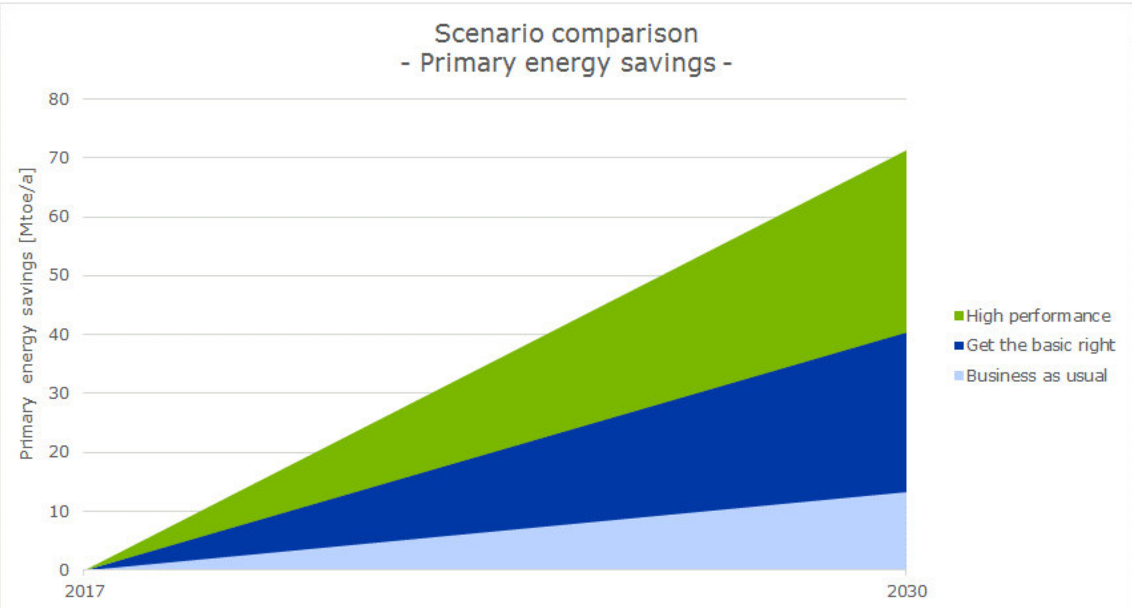

Figure 4: Scenario comparison, maximal potential reductions by TBS scenarios, Mtoe primary energy per year

[53] See Annex 6.1.1 (CO_2 emission factors) and 6.1.2 (primary energy factors).

The results show that actually applying renewal, replacement or upgrade of technical building systems for the optimisation of these systems as intended by EPBD Art. 8 – which currently by far is not done across the EU - enables **significant** additional CO_2 reduction and primary energy saving potentials until 2030.

The total CO_2 reductions of implementing a *High Performance* scenario according to the intention of EPBD Art. 8 add up to about 156 Mt CO_2 emission reductions and 71 Mtoe primary energy savings annually in 2030. As we estimate an annual 30 Mt CO_2 emission reductions and 13 Mtoe primary energy savings of these reductions to happen in the BAU case anyway in 2030, the *additional* reductions a High Performance track (which includes getting the basics right) could deliver is estimated to be about an annual 126 Mt CO_2 emissions and 58 Mtoe primary energy in 2030. Due to the assumption of a constant implementation rate of 3.6% for the packages in the building stock, these annual reductions gradually build up over the period 2017-2030. Looking at the *Get the basics right scenario, additional* annual reductions of **61 Mt CO_2** emissions and **27 Mtoe primary energy** could be achieved on top of BAU in 2030. Thus the estimated difference between the additional annual reductions the *High Performance* scenario can achieve on top of the *Get the basics right* scenario is about **65 Mt CO_2** emissions and **31 Mtoe/year primary energy** in 2030. These additional reductions are mainly driven by advanced building automation and control systems (BACS).

Table 10: Additional annual CO_2 and primary energy savings in 2030 compared to a Business-As-Usual scenario

Scenario	CO_2-emissions reduction [Mt CO2/year]	Primary energy savings [Mtoe/year]
Get the basics right	61	27
High performance	126	58

These reductions are very significant, which can be illustrated by some similar numbers for comparison.

- The *no change option* (BAU) of the EPBD impact assessment[54] foresees a reduction of the annual CO_2 emissions of approx. 154 Mt between 2017-2030.
- Additional reductions through the proposed EPBD (preferred option II) are to yield an annual **38 Mt CO_2** emission reductions and **30 Mtoe primary energy** savings by 2030.
- Additional reductions through the policy option III that includes mandatory renovation are to yield an annual **134 Mt CO_2** emission reductions and **74 Mtoe primary energy** savings by 2030.

Both *Get the basics right* and *High Performance* scenarios require to significantly step up the actual implementation of Art. 8 across EU Member States. If this would be the case, the full implementation

[54] Impact assessment EPBD: COM (2016) 765 final}, {SWD(2016) 415 final}

of *Get the basics right* might well exceed the communicated reductions of 38 Mt CO_2 emissions (61 Mt CO_2 per year) and nearly equal the primary energy savings of 30 Mtoe (27 Mtoe primary energy) by 2030 to be achieved with the proposed draft EPBD. The potential reductions of the advanced and more ambitious *High Performance* scenario ranges even only slightly below the reductions of Option III (mandatory requirements on annual renovation rates at EU level), which has been assessed during the EPBD impact assessment. Note that Option III is very ambitious, too, and would have required mandatory renovation.

As to the Get the basics right scenario it should be emphasized that it consists of very cost efficient basic measures, i.e. they require comparatively low investment and have short payback times. They can be seen as "low hanging fruits", as they really should be picked while causing "no regret", This means they do not "hinder" further potential longer-term reductions and thus do not create long-term lock-in effects.

The following table shows the total investments needed and the achievable energy cost savings (each per year) for the two scenarios on EU level.

Table 11: Scenario comparison, investment costs and energy cost savings in billion Euro per year

Scenario	Investment costs [bn Euro/year]	Energy cost savings[55] [bn Euro/year]	Payback [years]
Get the basics right	5.6	2.8	2.0
High performance	24.8	5.2	4.8

The 5.6 billion Euro in the *Get the basics right* scenario are invested once in a specific year, the energy cost savings are assumed to be achieved from this specific year of the investment onwards in every year.

[55] EU28 energy cost averages from 2017 to 2030 as used in EPBD impact assessment (Gas: 5.9 ct/kWh; District heat: 9.6 ct/kWh; Electricity: 21.9 ct/kWh. In the EPBD impact assessment district heat was assumed to have an annual price increase of 2.59% across the EU, which is in between the price increases that were assumed for gas, oil and coal.)

5 Major findings, conclusions and policy recommendations

5.1 Overview of findings

This section presents a short summary of our major findings from the analyses presented in the previous chapters:

3) **Underestimated climate benefit of basic TBS optimisation on EU level.** If optimisations happen by applying *Get the basic right* packages the corresponding *Get the basics right scenario* yields up to an additional annual 61 Mt CO_2 emission in 2030 compared to BAU. This is almost 60% more of what is to be achieved in total with the proposed revision of the EPBD. As to primary energy we estimate savings of up to 27 Mtoe
4) **Even more climate benefits of advanced TBS optimisation on EU level.** If optimisation happens by applying *High Performance* packages the corresponding *High Performance scenario* yields up to an additional annual 126 Mt CO_2 emission reduction and 58 Mtoe primary energy savings in 2030 compared to BAU.
5) **Article 8 does not deliver yet.** This means a significant savings potential lying in the optimisation of the energy use of technical building systems is not exploited. The latest report of the Concerted Action EPBD provides sufficient evidence that this is due to quite incomplete implementation at national level. There is a lack of clearly defined system requirements for new, replacement and upgrade of technical building systems in existing buildings as well as a lacking common understanding about the kind of measures needed to meet Article 8 requirements. Sometimes requirements only exist for *major* renovations rather than for *any* renovation of TBS in existing buildings, sometimes there are only requirements for single components of systems, rather than for the whole system.
6) **Single measures as a starting point.** In this study, several single measures which would belong to a proper implementation of Article 8 have been analysed for a set of typical existing buildings (residential and non-residential) which we call "reference" buildings. In all reference buildings, most of these single measures have a very short payback period, typically of less than 5 years and for several measures of significantly less than 5 years (e.g. thermostatic valves, boiler and pump adjustments, night setbacks or room air temperature control for ventilation and occupancy and daylight control for lighting).
7) **No-brainer-measures.** Some of the single measures, having a very short payback time, are very easy to implement as stand-alone measures. This means they are not necessarily bound to the implementation within a package. The most prominent measures in this context are the exchange of thermostatic valves and hydronic balancing. They imply indoor air temperatures being closer to occupants' needs, lower power consumption of heating pumps, lower water temperatures in the heating circuit, thus less distribution losses and higher efficiency of heat generators.

8) **Packages of measures preferred.** Single measures have been bundled to reasonable optimisation packages, as it obviously creates economic synergies to implement several single measures at once. While the *Get the basics right* package bundles measures with very short payback times, that should be implemented in every renewal, replacement or upgrade of TBS, the *High Performance* package also includes more advanced measures, mainly for building automation and control (BACS). Savings potentials of the optimisation packages for total final energy are significant and, depending on the reference building, range between 14% and 34% for *Get the basics right* packages (with an average of 22%) and between 33% and 49% for *High performance* packages (with an average of 38%). In a potential world where *High performance* packages would have a significant share this may lead to average savings of TBS packages in the order of magnitude of 30% (if the status of the building is comparable to the defined reference buildings).
9) **An economic temptation.** Across all building types G*et the basics right* packages have a payback of on average 2.0 years, while we calculated an average of 4.8 years for the *High performance* packages. We consider both payback times to be very short. We estimate that compared to 2017 energy consumption levels annual energy cost savings could build up to 36 billion Euro by 2030, if G*et the basics right* packages would be implemented consistently. In a world where only *High Performance* packages would be implemented consistently, annual energy cost savings could build up to 67 billion Euro by 2030.
10) **Vast unexploited potential in the EU**. *Compared to* a Business-as-Usual (BAU) scenario where current EPBD provisions are continued without any further changes the additional annual primary energy savings and CO_2 reductions at EU level grow from year to year. In order to estimate the impact a proper implementation of Article 8 may have at EU level, we assume that between 2017 and 2030 *in each year* in 3.6% of the EU28 building stock (i.e. altogether 47%) TBS are optimised according to Article 8. It means that we assume unexploited potentials for optimisation of TBS in far more than half of the European building stock. As usual in scenario building, it is assumed that optimisations will happen in the least efficient buildings first, due to shortest payback times.

5.2 Conclusions

From our findings the following conclusions can be drawn:

A consequent optimisation of the energy use of technical buildings systems whenever they are built new, replaced or upgraded would yield significant final energy savings of up to 20-40%. This is because so far even basic low-invasive measures that require low investment have been rarely implemented. On average, packages of basic measures can yield well above 20% savings. An inclusion of advanced BACS may boost this number to almost 40%. In both cases in this study the starting point is a moderately insulated reference building with a new, but non-optimised heat generator that meets Ecodesign requirements. The new heat generator serves as a trigger for the optimisation of the energy use of the TBS. There is no precise evidence about the actual status of TBS across Europe. Yet we think to be on the safe side by assuming that until 2030 47% of the building stock is actually available for optimisation of TBS and being similar to our reference buildings as to insulation level and (non-optimised) technical building systems, i.e. buildings where the savings that we calculated for the packages can actually be achieved.

Potential energy savings and CO_2 reductions of basic but large-scale optimisation of technical building systems equal or even outperform the newly released EPBD proposal. Our results show that proper implementation of Article 8 *alone* could create the same or even more energy savings and CO_2 reductions than the whole set of "targeted amendments" the EC has proposed in their winter package's draft EPBD. This is a striking result which shows that optimisation of TBS is one of still unexploited no-regret solutions to swing into a "well below 2°C" path.

Optimisation of technical building systems quickly delivers significant savings without creating lock-in effects: cumulated CO_2 emissions from building operation could be reduced by roughly 400-800 $MtCO_2$ until 2030 (compared to 250 $MtCO_2$ by the proposed revision of the EPBD). This is why TBS need to be optimised faster. A basic premise of this study is that optimisation of technical building systems could take place at a rate between 3%-4%. We derived this rate from taking the rate of exchange of heat generators as a proxy. The operation of these new heat generators needs optimisation, too and is part of the various optimisations we considered. 3%-4% is approximately three times the current renovation rate of buildings. Yet, we think it is realistic due to relatively low investment costs and short payback times of technical building systems' optimisation. Yet, of course, even at high rates, optimisations of TBS need to exploit their full savings potential. This is key to not "waste" savings potentials and to not lock-them in until the next renovation cycle. We'd like to emphasize that quick savings that do not create lock-in effects significantly help to reduce *cumulated* emissions which are the key driver for climate change.

Both implementation of and compliance with EPBD Article 8 "Technical building systems" need to improve significantly. While Article 8 of the current EPBD theoretically aims at unleashing a very attractive savings potential, Article 8 does not yet deliver due to inadequate national implementation. This study did not allow an in-depth screening of the implementation at national level, yet the following drawbacks became evident: lack of clearly defined requirements, no common understanding of actual savings potential, focus on components rather than on systems, focus on *major* renovations rather than on *any* renovation of TBS.

More guidance is needed on how to interpret Article 8 and how to define system performance. This is to remove uncertainty about how to apply it on the national level and to boost the so far only modest impact of Article 8 on building energy performance. Member States especially struggle with system requirements that have to be set in respect of the overall system performance. It is current practice to set requirements on component level; in rare cases attempts are made to define requirements e.g. on the level of the heating system. There is no common understanding on how system requirements for a combination of systems may be defined.

A common understanding needs to be created on how to calculate the potential savings of optimised technical building systems. While working on this project we have had several discussions with experts, reviewed literature and performed plenty of calculations using certified software with the objective to determine the actual savings potential of optimising technical building systems. It has turned out that it is of utmost importance to agree on a common baseline where savings are counted from. Yet, studies sometimes do neither exactly state the baseline nor record all parameters which determine the buildings' energy consumption. Sometimes it is even unclear, whether savings apply to a specific case or if savings are meant to be scalable e.g. to EU level.

Optimisation of technical building systems significantly helps to close the often observed performance gap during stepwise renovation towards nZEB level. Most energetic renovations are done step-by-step. In many cases one of the first measures is the installation of a new heat generator. With each additional renovation step the heat generator gets ever more oversized and the whole system will run more and more under part load conditions. An optimised building system will be able to efficiently handle part load conditions.

Optimisation of technical building systems supports the persistence of energy savings. In the calculations we performed within this study we assumed that initial savings will persist over the lifetime of a measure. This is because optimised building systems are better able to handle varying conditions, because optimisation also includes revolving maintenance and because advanced systems including BACS may have the ability to check and signal mal-performance or even autonomously adjust parameters to avoid efficiency losses. This is also known as continuous commissioning.

Via building automation and control systems (BACS) technical building systems get an active, manageable part of the transforming energy system, offering more flexibility options. This opens up savings potentials beyond buildings' walls and increases the importance of buildings being ready for smart operation within the energy system. Within this study we focused on savings technical building systems including building automation and control can deliver within the boundaries of a building. Although we not only considered direct emissions from the building but also indirect emissions within the power system caused by the buildings' power consumption, direct emissions dominate in our scenario. In the longer run, this will change. More buildings are expected to be heated by electric heat pumps, more buildings will not just consume but also produce power (PV, micro-CHP), and more buildings will serve as charging point for electric cars and exchange power with cars. In a nutshell buildings' impact on the energy system's operation and emissions following from that steadily increases. BACS are an enabler for that development.

Optimisation of technical building systems and improving the energy performance of building envelopes needs to go hand in hand to reach climate targets and to significantly increase the number of nZEB. Although this study deals with the savings potential of technical building systems, savings strategies need to focus on synergies between different technologies, aiming at the building's comfort and efficiency (*technical building systems and building envelope*), the interplay with on-site renewables and on managing the building's usefulness within the overall energy system. Due to the very high ambition level the question is not which technological solution should dominate but how to integrate all available solutions in the best way for making the target.

5.3 Policy recommendations

In the following we provide some ideas for how policy could help exploit the immense savings potential of optimised technical building systems including building automation and control.

The ongoing revision of the EPBD should be used to give a significant push to a substantial increase of rate and depth of technical building systems' optimisation. As with other political targets this should be achieved by means of a mix of push and pull measures.

- A **push** could be exerted by sharpening Article 8 requirements: so far Article 8 mentions requirements for the overall systems performance, for proper installation, appropriate dimensioning, adjustment and control. Yet it does not link these requirements to functionalities of TBS like the control of energy generation, distribution and emission of heating and cooling. As the EPBD usually does not set requirements to install certain products, this might be a way to make "overall system performance requirements" more concrete by breaking it down to functionalities. Some of the very short payback, no-regret options could be explicitly made mandatory, accompanied by a deadline for implementation. In this context we would like to highlight controls for room temperature which in our opinion are a "conditio sine qua non" for empowering consumers to act on feedback from consumption based billing for space heat, which is required by the Energy Efficiency Directive.
- A **pull** could e.g. come from modified Energy Performance Certificates (EPC) which not only give the overall building energy performance but also distinguish between the energy performance of TBS and the building envelope. Ideally EPCs would need to be updated following the assessment of the overall energy performance of the complete altered TBS whenever they are upgraded, installed or replaced. Such assessment is suggested by the European Commission in the proposal for the revision of the EPBD. On a national level this could be incentivised by programs like the German "Optimisation of heating systems (Heizungsoptimierung)" in existing buildings which provides non-repayable grants. Another pull, especially for more advanced TBS, could be generated by a proper design and successful implementation of the "smartness indicator".

The ongoing revision of the EPBD should be used to provide more guidance on Article 8. Our research showed that there is quite some confusion amongst stakeholders about the meaning of technical building systems and about how to determine and steer their performance. This is one of the reasons for the observed under-investment despite potentially very short payback times. According to the EPBD impact assessment "timid recommendations in Article 8 of the EPBD have not been sufficient to overcome barriers preventing the integration of technical progress on key enabling technologies for 'smart buildings'". We recommend that the Commission should provide a communication providing systematic advice on how to interpret the terms used in Article 8 and give examples. Above all the difference between components / products and systems needs clarification, but also in which cases an "overall" performance requirements comprising heating, hot water, air-conditioning (cooling) and ventilation should be set up and where performance requirements for sub-systems like heating or for functionalities suffice or work better. For a common understanding even basic terms like "system" and "overall energy performance" including new terms like "recharging points or "smartness indicator" should be included. Ideally these definitions should be in line with corresponding CEN standards for the energy performance of buildings.

Last but not least such guidance may be complemented by a set of best practice examples from across Europe where the potential of technical building systems including automation and control for the optimisation of existing buildings operation has been exploited in a cost-optimal way. These examples should also provide details about how the evaluation of savings should be designed in order to get a valid and credible determination of the actual savings caused by the optimisation.

The EC should actively promote a harmonisation of standardisation activities around technical building systems and Ecodesign activities around products being part of technical building systems including automation and control. So far Technical Committees e.g. under Mandate M480 elaborate European standards (CEN EPB standards) for the calculation of the energy performance of buildings. This includes standards for the calculation of systems efficiency. The calculations rely on a number of input parameters from products being used in building systems. Ecodesign deals with minimum energy performance requirements for products. For this purpose, product standards for testing the products or determination of their energy efficiency respectively are set up. Yet so far the product fiches produced in this context often do not provide the full set of information that would be needed for a proper consideration of a *product* in the calculation of the *systems* performance. Therefore, better harmonisation needs to be achieved in the way, that product standards deliver the needed inputs for systems performance calculations and that designers of product standards are made aware of and then obliged to include the parameters needed for the calculation of systems performance.

The revision of Article 8 should be more explicit about the minimum performance requirements for technical building systems and their timing. It could be supported by EPBD Annex I about ways to express it. The overall energy performance of the building can be illustrated as a two-step process: a) How big is the energy need for providing the actually needed energy services (like a comfortably heated room during presence of occupants)? b) How much CO_2 and/or primary energy and/or delivered energy is needed for that? The factor between a) and b) is determined by the overall efficiency of the technical building systems. It could be required to split up the energy performance indicator which is already required by EPBD Annex I, Article 2 into a) an explicit performance indicator for heating and cooling needs and b) a "climate (CO_2)" or less preferably "primary energy" systems performance factor. While a) characterises the energy efficiency of the building envelope b) characterises the efficiency of the building systems. This proposal is in line with proposals that have been made e.g. in [ECOFYS, 2013] and [Pehnt et al., 2012]. A) and b) could be part of the energy performance certificate.

According to Article 28 EPBD minimum energy performance requirements for technical building systems should have been in place and applied since July 2013. Yet, this is not the case in many Member States. Therefore clarifications and guidance are needed immediately to make up for the significant delay in the implementation of Article 8.

The EC should encourage Member States to clearly address the most efficient order of measures in their national long-term renovation strategies. As pointed out before, climate policy is not about reaching a certain annual CO_2 emission by 2050, but it is about not overspending the total CO_2 emission *budget* we have until 2050. Therefore, long-term renovation strategies need to show cumulated emissions till 2050. This will trigger a more in-depth assessment of the best possible order of measures within a package for reducing CO_2 emissions from the building stock. Obviously in this context it is important to consider in the ranking of measures how fast they can deliver savings without compromising the savings potential of subsequent measures. It can be assumed, that optimisation of technical building systems will be ranked high in this context for two reasons: as pointed put TBS can a) yield fast savings and b) support the persistence of energy savings, specifically in step-by-step renovations to sustainable (nZEB) consumption level. Yet still these measures need to be considered as part of packages. Cost-benefit analyses should always be conducted for whole packages that meet climate targets – and not for individual measures being part of these packages - even if these packages will be implemented step-by-step rather than at once. This goes for individual buildings and the whole building stock. Most measures for saving energy in the building stock save a certain *percentage* of energy. Let's assume the replacement of an old boiler by a new efficient one. Roughly spoken the new boiler will save e.g. 20% of the previous consumption – regardless whether it has been installed in a well-insulated or poorly insulated building. Thus the same measure seems to have a very different cost-effectiveness depending on when it is implemented and eventually may appear inefficient when implemented at the end of a step-by-step process where there is not much left to save. Falling into this trap needs to be avoided explicitly when determining the "best for climate" order of measures.

With the strong advent of advanced building and connected automation and control systems (BACS) already stipulated in the proposed draft EPBD the Commission should specifically provide further guidance on BACS for supporting their proper implementation. This could encompass

- guidance on best practice BACS solutions by building type
- guidance on the assessment of cost optimal BACS solutions (to support MS in their determinations of cost optimal building codes) and derive analytical templates that MS can use to determine which BACS measures or capabilities should be *mandated* within their building energy codes for new buildings, building renovations and renewal or renovations of the technical building systems

The smartness indicator proposed by the Commission will need to have the part which addresses BACS fully developed to address and grade all the pertinent BACS solutions. This will enable the possibility of minimum BACS scores within a smart readiness indicator being used as the basis for setting minimum requirements within building codes.

BACS capabilities that have been addressed in the proposed revision of the EPBD need to be properly analysed and developed. The specific capabilities of functionalities that facilitate to optimize, and maintain over time, energy performance of larger residential and non-residential buildings should be analysed and developed in a template that MS can adapt to their circumstances (e.g. to reflect local energy price differences and service delivery capabilities). This should also be tied to the part of the smartness indicator methodology that addresses BACS.

The potential of TBS including BACS to assess the progress in national renovation roadmaps should be assessed further. There is a strong need to monitor the progress in energy efficiency of national building stocks for the evaluation of the effectiveness of policy measures. Developments like the internet of things (IoT) open up new options for monitoring which have been unimaginable until recently. A part of the potential already has been addressed in the proposed revision of the EPBD by proposing advanced TBS for inspection of heating systems and air-conditioning systems. Further use for monitoring e.g. by a closer interlinkage with the EC's Buildings Observatory seems to be possible and should be further discussed.

The EED could flank the EPBD in facilitating the proper implementation of BACS. Beyond the EPBD the Commission could encourage Article 7 of the EED (addressing Energy Efficiency Obligation Schemes for energy suppliers) to be implemented in such a manner that BACS measures are directly recognised and are eligible for funding via the EEOS (or the alternative schemes that MS must implement if not implementing and EEOS). To facilitate this, deemed savings methodologies for different BACS solutions could be developed and promoted for use within such schemes. These deemed savings methodologies could also be tied to the methodology to be developed for the Smartness Indicator. Furthermore, MS could be encouraged to implement EED article 16 on the availability of qualification, accreditation and certification schemes in such a manner that supports the development of qualified and accredited service provision to address the current skills gaps in the specification, installation and commissioning of BACS and to support delivery efforts managed under the Article 7 EEOS or related schemes. To ensure that the EPBD and EED provisions are fully informed, coordinated and complementary the Commission should consider requesting that the Concerted Action groups for both Directives designate working parties to look at these issues and aim to host joint meetings to discuss how they should best be addressed.

Thus the basic vision is that the existing policy frameworks would be adapted to support the rapid but prudent implementation of optimised technical building systems and minimum BACS capabilities. Ideally BACS would be rolled out at least the pace by which the technical building systems are replaced through the use of minimum requirements in building codes that are linked to the BACS assessment. In addition, programmes to support the roll-out of BACS will be developed via the auspices of national Energy Efficiency Obligation Schemes or similar, to help ensure best practice BACS as part of optimised technical building systems are installed as rapidly and as cost effectively as possible. These schemes should also be complemented by measures to ensure capacity and quality in the supply chain and service delivery.

6 Annex

6.1 Annex 1 - Input data

6.1.1 CO_2 emission factors

Table 12: CO_2 emission factors, EU28[56]

[g CO_2/kWh]	2017	2020	2025	2030
Natural gas	202			
District heat	140	124	101	82
Electricity	327	293	245	204

6.1.2 Primary energy factors

Table 13: Primary energy factors, EU28[57]

[-]	2017	2020	2025	2030
Natural gas	1.0			
District heat	0.65	0.59	0.50	0.42
Electricity	2.31	2.11	1.80	1.54

6.1.3 Allocation of building stock for the extrapolation

The following table gives an overview of the allocation of different building types within the European building stock to the investigated reference cases and their relative share within the building stock (residential and non-residential). The extrapolation is based on this distribution.

[56] Natural gas: IPCC, 2006
District heat: Own calculation from Eurostat energy statistics
Electricity: ENERDATA, 2013-2015
Average annual decrease of CO_2 factors according to target corridor for power sector corresponding to "A Roadmap for moving to a competitive low carbon economy in 2050

[57] Eurostat Complete Energy Balances, IPCC 2006; ENERDATA, 2013-2015; For district heat and electricity: Own calculations based on Eurostat Complete Energy Balances; ECOFYS, 2013; The PE-factors are total primary energy factors, including renewables.

Table 14: Allocation of building stock to reference buildings for extrapolation of results

Reference building	Allocation of building stock to reference building	Share of allocation in residential / non-residential stock	Residential and non-residential building stock
SFH Gas	100% SFHs of all energy carriers	60% of residential building stock	100% (≈ 19.6 billion m²)
MFH Gas	100% MFH Gas and Coal 90% MFH Oil and Biomass	32% of residential building stock	
MFH District heating	100% MFH District heating	4% of residential building stock	
MFH Heat pump	100% MFH Heat pump, Direct electricity, Solar thermal and Geothermal 10% MFH Oil and Biomass	4% of residential building stock	
Office standard	80% Offices, Education, Other, Hotels and Health	60% of non-residential building stock	100% (≈ 6.9 billion m²)
Office advanced	20% Offices, Education, Other, Hotels and Health	15% of non-residential building stock	
Supermarket standard	80% Stores with refrigeration units	1%[58] of non-residential building stock	
Supermarket advanced	100% Retail minus 80% Stores with refrigeration units	24% of non-residential building stock	

[58] As the reference building „Supermarket standard" only reprents a small part of the total non-residential building stock (80% of the supermarkets, supermarkets represent only a small share of the subcategory „Retail" of the non-residential building stock), it is only allocated to about 1% of this stock.

6.2 Annex 2 - Optimisation measures & packages

6.2.1 List of optimisation measures

Table 15: Overview of investigated measures in single-family and multi-family buildings

EPBD Article 8 aspect regarding	Measures
1. Appropriate dimensioning	- Proper dimensioning of pump (space heating) - In case of MFH (in case of circulation), proper dimensioning of circulation pump
2. Proper installation	- Pipework of space heating distribution system: Better insulation in accessible non-heated zones (assumption 90% accessible): o *Get the basics right* scenario: 100% of pipe diameter o *High Performance* scenario: 200% of pipe diameter - Pipework of DHW distribution system: Better insulation in accessible non-heated zones (assumption 90% accessible): o SFH (one pipe distribution): 100% of pipe diameter o MFH (circulation): 100 % of pipe diameter
3. Adjustments	- Night setback – adjusted settings (from 11 pm to 6 am, 2 K temperature reduction) - Adjustment of system temperatures (supply/return) - DHW at SFH: temperature reduction (switch off of storage charging pump) during night time (between 11pm and 6am) - DHW at MFH: commissioning of thermal balancing valves on circulation lines, circulation required 24 hours - Hydronic balancing (manual) - Installation of standard thermostatic radiator valves (TRV) - MFH: Automatic hydronic balancing
4. Automation, control and monitoring systems	- Boiler: use weather compensation - Boiler: optimum start/stop - Pump management: variable speed/flow - Installation of electronic thermostatic radiator valves (eTRV) - MFH: automatic thermal balancing valves at DHW circulation lines - Control of heat emitters provided by individual room control sensing external temperature, room temperature and thermal response (optimum start/stop) with communication: between controllers and BACS (e.g. scheduler); automatic control of distribution network hot water temperature (supply or return) via compensation; VSD control of distribution pumps

Table 16: Overview of investigated measures in office buildings and supermarkets

EPBD Article 8 aspect regarding	Measures
1. Appropriate dimensioning	- Proper dimensioning of pumps (space heating and cooling)
2. Proper installation	- Pipework of space heating distribution system: Better insulation in accessible non-heated zones (assumption 90% accessible): o *Get the basics right* scenario: 100% of pipe diameter o *High Performance* scenario: 200% of pipe diameter
3. Adjustments	- Adjustment of pump volumes (space heating and cooling, automatic) - Adjustment of system temperatures (space heating and cooling) - Adjustment of air volumes to actual demand - Adjustment of heating and cooling supply (night/holiday/weekend switch-off) - Thermostatic radiator valve (TRV)
4. Automation, control and monitoring systems	- BEMS system o User-friendly BEMS system in place but with energy savings functions activated. Runs diagnostics, reports faults and provides informative displays of energy consumption, indoor conditions and possibilities for improvement. Heating - Automatic balanced distribution hot water network via PIBCVs - Automatic thermal balanced DHW circulation lines and network - Temperature (supply or return) with weather compensation - Optimum start/stop - Variable speed pump controls for network distribution pumps with constant Δp - Staging of generators based on order of efficiency (for supermarket case only) - Individual heat emitter control (eTRVs office building with radiators) - Individual room/zone demand driven control with communication between controllers and BACS and presence detection - Heat recovery controls (supermarket with heat recovery) Lighting - Lighting control per task light source using occupancy and daylight responsive controls with dimming and daylight responsiveness for circulation lighting Cooling - Automatic balanced distribution cold water network via PIBCVs - Variable airflow and chiller capacity by means of variable speed drives on ventilation fans and chiller compressor. - Temperature (supply or return) with weather compensation - Optimum start/stop - Variable speed pump controls for network distribution pumps with constant Δp

EPBD Article 8 aspect regarding	Measures
	- Control of emitters provided by individual room demand control with communication and presence detection <u>Ventilation</u> - Air flow control at the room/zone level via demand control: wherein the system is controlled by sensors measuring indoor air parameters or adapted criteria (e.g. CO_2, mixed gas or VOC sensors). - Air flow or pressure control at the air handler level via automatic flow or pressure control with demand evaluation - Advanced air supply and humidity controls

6.2.2 Discussion of other studies: Optimisation measures

When having a look at the results of the single measures, there may be different results for the same measures depending on various aspects of the study such as the aim of the study, the baseline and underlying assumptions. We show exemplarily by the measure radiator valve what the differences are and how they can be explained. The aim is to get a better understanding of the savings that are calculated in the present study and how they are comparable to the results of other studies.

Basically, the savings of the same measures are not necessarily comparable when neglecting the differences in the set up. Important criteria that lead to differences are:

- What is the baseline? (Against what is the measure compared?
- Changes of dwellers (Is there a change in behaviour due to the change?)
- Empty flats (Have there been empty, i.e. flats that have not been heated?
- Energy poverty (Is the energy consumption economically driven, i.e. are there cases where people due to a measure, e.g. a new temperature control, stop heating the flat due to costs?)
- Ventilation behaviour (How do people ventilate the flat? Does the behaviour change?)
- Indoor air temperatures (What is the desired temperature?)
- Outdoor temperature
- Energy prices (What is the change in energy prices? Increasing energy price may lead to less energy consumption to prevent increased hating costs for the dwelling)
- Solar irradiation (Is solar irradiation taken into account?)

Please note that the baseline of this study includes all services covered by the EPBD, i.e. space heating, space cooling, ventilation, domestic hot water and lighting (for non-residential buildings). This is further explained in Annex 6.2.3. It implies that numerical values of space heating energy saving, expressed as a percentage, are always smaller in this study, compared to the other studies

Basically, we look at three studies and compare them:

- Ecofys' study for EUnited Valves: Energy & CO_2 emission savings potentials of thermostatic valves [ECOFYS, 2016a][59]
- Study from Prof. Hirschberg: Energy efficiency related to the change of thermostatic radiator valves [Hirschberg, 2016][60]
- The present study

The EUnited valves study shows a higher savings potential than the present one which can be explained by the baseline differences. The main differences are simple radiator valves as baseline compared to old thermostatic valves and additional savings in the EUnited study due to the assumption that 50% of the cases at the same time perform a manual hydronic balancing when exchanging the radiator valve. The Hirschberg study has differences in the approach (see below), but the order of magnitude of the savings when using the same baseline (old thermostatic valve) is comparable.

[59] The full study is available upon request from either Ecofys or Danfoss A/S.
[60] The full study is available upon request from either Ecofys or Danfoss A/S.

The EUnited valves study

Key differences

Regarding the EUnited valves study[61], the key difference of the two studies is that the EHI study compares the potential energy savings if a simple radiator valves (SRV) is exchanged by a thermostatic radiator valve (TRV), including hydronic balancing in 50% of the cases. The present study compares the exchange of a thermostatic radiator valve before 1988 (with unprecise control) with the installation of standard thermostatic radiator valves isolated, i.e. without including savings from manual hydronic balancing. The selection of a TRV before 1988 as reference case is assumed to be a good proxy for the "EU average" radiator valve (see chapter 3.2.1).

Summary of the study

The study

- shows potential energy savings if simple radiator valves (SRV) is exchanged by thermostatically controlled valves (TRV)
- differentiates between different building types (old / young and SFH /MFH) and different climate zones
- executes calculations according to reference building
- calculates a saving potential of 13-19%

The EUnited valves study specifies 4 reference climate zones and defines 4 reference buildings per climate zone, which represent the stock of residential buildings of the countries allocated to the respective climate zones. On this basis the study calculates for the reference climate zone C (Central Europe) the reductions of the energy demand for heating, resulting from replacing simple (manual) radiator valve (SRV with thermostatic valve, according to [DIN V 18599-5, 2011] and therewith the average change of the room temperature is calculated for the heating period using the planning package for passive houses (PHPP). On this basis, the average room temperature that result from replacing the radiator valves, is projected for the 16 reference cases (four reference climate zones with four reference buildings each) and the savings are calculated per reference building. The savings on European level are in the range of **13-19%.**

Hirschberg study

Key difference

Regarding Hirschberg study the key difference is the calculation approach and the baseline. Hirschberg compares different operation modes and simulates the energy savings for different scenarios by suing a simulation software. The present study uses a normative approach based on reference buildings.

[61] ECOFYS, 2016a

Summary of the study

In his study, Hirschberg takes a user profile for using the manual radiator valve into account and executes a real-time simulation. He compares different operation modes and calculates the energy savings for different scenarios, the exchange of different thermostatic valves, "energy expenditure factors" for emission and control and for heat production. The study shows the potential for energy savings due to exchanging radiator valves and operation mode. Energy savings can be achieved by changing the operation mode from a continued (always at the same temperature = 21°C) mode to a mode matched to the inhabitant's lifestyle (set back temperature by night, while people sleep and during the day, while people are working). Instead of SRV and TRV, 8 different types of thermostats / thermostatic valves are analysed: RAW 5010 (liquid sensor), certified TRV (limits), electronic, pressure value, boiler controlled, old sensor liquid, old sensor gas, manual. For replacing SRVs by modern TRV the energy savings are 36%, when replacing old TRV by modern TRV its is 8%.
For electronic TRV (eTRV), the study evaluates savings under different assumptions for setback. The range for replacing SRV by an eTRV is between 37% and 46%. In the case of replacing an old TRV by an eTRV, the study evaluates savings between 12% when setback is already provided, to 23% when setback – night setback and further setback during working hours – is implemented by the eTRV.

The present study

Regarding the TRV, in the present study the baseline is a thermostatic radiator valve (TRV) before 1988. This TRV is likely to map the most common radiator valve type in Europe as thermostatic radiator valves according to the Consultic study[62] represent approximately 56% of the radiator valves in Europe (simple radiator valves: 39%).

As described in 3.1.1 the study uses reference buildings to represent a good proxy for the average EU building stock. The objective of this study is to calculate the effects of optimisation packages on EU level and determinate the saving potential. It is not to calculate the savings for one single measure (as e.g. the TRV valve) for different options (e.g. changing from manual to TRV in an old building, changing from TRV to eTRV in a new building, to change from a TRV before 1988 to an eTRV in an old building etc.) and conclude on which replacement would be the one with the highest saving or the shortest payback period. Thus, the selection of a TRV before 1988 has been chosen to be a good proxy for the radiator valve. This contains the stock of manual radiator valves as well as the TRV (including electronic TRVs) in the stock. The savings have been calculated according to EN 15232 and 15316 for the building automation and control systems (BACS) and according to DIN V 18599. The DIN V 18599 ensures CEN-EPBD conformity (see chapter 3.1.3). For self-acting thermostatic radiator valves (TRV), we calculated savings (according to DIN V 18599) which resulted in up to 7% savings. For electronic thermostatic radiator valves as a single measure we calculated savings up to 11% - not considering night setback or hydronic balancing. For night setback as a single measure we calculated savings up to 10%. However, we did not calculate additional savings stemming from setback during working hours. Considering these effects we conclude that the results of this study for moving from

[62] Consultic, 2015

an old TRV to a modern self-acting TRV or eTRV respectively as a single measure are similar to the results of Hirschberg.

The following table gives an overview of the calculated saving potential and key facts of these studies:

Table 17: Overview of the differences of three different studies related to energy saving potential

Studies	Target	Approach	Savings	Change to thermostatic radiator valve (TRV or eTRV) from	Calculation method
Present study	Calculate saving potential of optimisation measures of technical building systems on EU level	• Reference building • Optimisation measures ○ *Get the basics right* ○ *High performance* • Extrapolation to EU level	≤7% (TRV) ≤11% (eTRV) Without night setback	Old thermostatic radiator valve (before 1988)	Normative: DIN V 18599
EUnited Valves	Calculate energy and CO_2 emission savings of thermostatic radiator valves on EU level	• Reference building climate zones • Extrapolation to EU level	13-19% (savings include 50% manual balancing)	Simple radiator valve	Normative: DIN 18599-5
Hirschberg	Calculate effect of exchanging radiator valves and operation mode	Exchange of operation mode and eight different radiator valves	8% (TRV)	Old thermostatic radiator valve	Simulation: TRNSYS / Matlab
			36% (TRV)	Simple radiator valve	
			12% (eTRV)	Old thermostatic radiator valve; night setback in place	
			23% (eTRV), night & daytime setback	Old thermostatic radiator valve; no night setback	

6.2.3 Savings potential of individual optimisation measures

The following tables show the main results (final energy savings, energy cost[63] savings, investment, payback period) per single optimisation measure and shows whether the measure is part of the *Get the basic right* and/or *High performance* package.

Please note that the final energy savings (%) are based on the total final energy (heating, cooling, DHW, lighting, ventilation, auxiliary energy). Therefore, measures with a high impact within their category (e.g. occupancy control within lighting) can show saving percentages that may seem low at first sight as the space heating demand dominates the total final energy demand.

Table 18: Main results for all single measures of the reference single-family building

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High perfor-mance package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
Proper dimensioning of pump (space heating)	A	X	X	< 0.5%	40	-	0.0
Pipework of heating distribution system: better insulation (accessible at non-heated zones, 100% of diameter)	A	X	-	2%	40	200	5.0
Pipework of DHW system: accessible parts insulated with 100 % of pipe diameter)	A	X	X	1%	30	240	8.0
Pipework of heating distribution system: Better insulation (accessible at non-heated zones, 200% of diameter)	A	-	X	4%	70	220	3.0
Night setback - adjusted settings (from 11 pm to 6 am, 2 K temperature reduction)	A	X	X	5%	90	150	1.5
Adjustment of system temperatures (supply/return)	A	X	X	4%	60	150	2.5
DHW: temperature reduction (switch off) during night time	A	X	X	1%	20	150	7.5

[63] EU28 energy cost averages from 2017 to 2030 as used in EPBD impact assessment (Gas: 5.9 ct/kWh; District heat: 9.6 ct/kWh; Electricity: 21.9 ct/kWh). For further explanations see footnote 55.

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High perfor-mance package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
(between 11pm and 6am)							
Hydronic balancing (manual)	A	X	X	5%	80	440	5.5
Installation of standard thermostatic radiator valves (TRV)	A	X	-	5%[64]	90	270	3.0
Boiler: use weather compensation	B	-	X	10%	190	450	2.5
Boiler: optimum start/stop	B	-	X	8%	140	340	2.5
Pump management: variable speed/flow (delta p-variable)	B	-	X	< 0.5%	30	50	1.5
Installation of electronic thermostatic radiator valves (eTRV)	B	-	X	8%[65]	150	320	2.0
Control of heat emitters provided by individual room control sensing external temperature, room temperature and thermal response (optimum start/stop) with communication: between controllers and BACS (e.g. scheduler); automatic control of distribution network hot water temperature (supply or return) via compensation; VSD control of distribution pumps	B	-	X	28%	520	1.920	3.5

[64] See also discussion in Annex 6.2.2 on savings potential of thermostatic radiator valves.
[65] See also discussion in Annex 6.2.2 on savings potential of thermostatic radiator valves.

Three multi-family buildings only differing in the type of heat generators (gas boiler, district heating, heat pump) have been investigated. As the savings resulting from optimising the technical buildings system are mainly independent from the heat generator the joint results are presented in the following table.

Table 19: Main results for all single measures of the three reference multi-family buildings (considering gas, district heating and heat pump as heat generator)

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High perfor-mance package	Final energy savings (≤) [%]	Energy cost savings (≤)[66] [Euro]	Invest-ment [Euro]	Payback period (≥) [years]
Proper dimensioning of pump (space heating)	A	X	X	1 %	630	-	0.0
Proper dimensioning of circulation pump	A	X	X	0.5%	60	-	0.0
Pipework of heating distribution system: better insulation (accessible at non-heated zones, 100% of diameter)	A	X	-	1%	730	1,680	2.5
Pipework of DHW system (circulation): accessible parts insulated with 100 % of pipe diameter)	A	X	X	1%	700	1,680	2.5
Pipework of heating distribution system: better insulation (accessible at non-heated zones, 200% of diameter)	A	-	X	2%	1,250	1,900	1.5
Night setback - adjusted settings (from 11 pm to 6 am, 2 K temperature reduction)	A	X	X	10%	5,450	300	0.0
Adjustment of system temperatures	A	X	X	10%	5,540	300	0.0
DHW: commissioning of thermal balancing valves on circulation lines, circulation required 24 hours	A	X	X	0.5%	50	300	6.0
Hydronic balancing (manual)	A	-	-	7%	3,660	5,440	1.5

[66] Energy costs differ for the three heat generators (gas, district heat, heat pump). EU28 energy cost averages from 2017 to 2030 as used in EPBD impact assessment (Gas: 5.9 ct/kWh; District heat: 9.6 ct/kWh; Electricity: 21.9 ct/kWh). For further explanations see footnote 55.

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High perfor-mance package	Final energy savings (≤) [%]	Energy cost savings (≤)[66] [Euro]	Invest-ment [Euro]	Payback period (≥) [years]
Installation of standard thermostatic radiator valves (TRV)	A	X	-	7%[67]	3,850	4,410	1.0
Boiler: use weather compensation	B	-	-	9%	5,210	7,900	1.5
Boiler: optimum start/stop	B	-	-	7%	3,910	5,920	1.5
Variable control of heat generator capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control) (only relevant for heat pump)	B	-	X	15%	8,160	5,440	0.5
Pump management: variable speed/flow (delta p-variable)	B	-	X	0.5%	260	370	1.5
Installation of electronic thermostatic radiator valves (eTRV)	B	-	X	11%[68]	5,980	5,680	1.0
Automatic hydronic balancing[69]	B	X	X	10%[70]	5,760	6,660	1.0
Automatic thermal balancing vales at DHW circulation lines	B	X	X	4%	2,090	3,520	1.5
Control of heat emitters provided by individual room control sensing external temperature, room temperature and thermal response (optimum start/stop) with communication: between controllers and BACS (e.g. scheduler); automatic control of distribution network hot water temperature (supply or return) via compensation; VSD control of distribution pumps	B	-	X	26%	14,470	33,280	2.5

[67] See also discussion in Annex 6.2.2 on savings potential of thermostatic radiator valves.
[68] See also discussion in Annex 6.2.2 on savings potential of thermostatic radiator valves.
[69] The impact of hydronic balancing has been determined according to EN 15316-2-1:2007 which encompasses slightly lower average room temperatures (due to better control performance within the room) and lower pump energy consumption (mainly due to reduced flows). Note that poor balancing may also lead to poor efficiency of the heat generator (due to higher system temperatures) and/or higher room temperatures which are not included in the standard but (partly) covered by other individual measures in this study.
[70] Results on energy savings from real cases in the range from 8 to 15%; Source: Danfoss

Please note that the final energy savings (%) are based on the total final energy (heating, cooling, DHW, lighting, ventilation, auxiliary energy). Therefore, measures with a high impact within their category (e.g. occupancy control within lighting, pump management: variable speed within auxiliary energy, automatic hydronic balancing within cooling) can show saving percentages that may seem low at first sight as the space heating demand dominates the total final energy demand.

Table 20: Main results for all single measures of the reference office building (radiators)

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High performance package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
Proper dimensioning of pumps (space heating and cooling)	A	X	X	< 0.5%	270	-	0.0
Pipework of heating distribution system: Better insulation (accessible at non-heated zones, 100% of diameter)	A	X	-	< 0.5%	80	970	12.0
Pipework of heating distribution system: Better insulation (accessible at non-heated zones, 200% of diameter)	A	-	X	< 0.5%	140	1,080	7.5
Adjustment of pump volumes (automatic space heating and cooling)	A	X	X	< 0.5%	440	300	0.5
Adjustment of system temperatures (space heating and cooling)	A	X	X	< 0.5%	140	300	2.0
Adjustment of air volumes to actual demand	A	X	X	11%	4,800	2,800	0.5
Adjustment of heating and cooling supply (night/holiday/weekend switch-off)	A	X	X	1%	750	300	0.5
Heating: boiler - use weather compensation (supply/return temperature)	B	-	X	11%	3,260	8,100	2.5
Heating: optimum start/stop	B	-	X	18%	5,270	13,080	2.5
Heating - pump management: variable speed/flow (delta p-variable)	B	-	X	< 0.5%	230	410	2.0
Heating - control of heat emitters provided by individual room control with communication	B	-	-	18%	5,270	13,080	2.5
Heating - control of heat emitters provided by individual room control with communication and presence detection	B	-	X	25%	7,530	28,030	3.5

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High performance package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
Lighting - occupancy control	B	-	X	1%	1,080	1,930	2.0
Lighting - daylight control	B	-	X	1%	1,080	1,930	2.0
Cooling - use of weather compensation (supply/return temperature)	B	-	X	< 0.5%	300	540	2.0
Cooling - optimum start/stop	B	-	X	< 0.5%	420	750	2.0
Cooling - pump management: variable speed/flow (delta p-variable) (Variable airflow and chiller capacity by means of variable speed drives on ventilation fans and chiller compressor)	B	-	X	< 0.5%	150	260	1.5
Cooling - emitters control provided by Individual room control with communication	B	-	-	< 0.5%	400	720	2.0
Cooling - control of emitters provided by individual room control with communication and presence detection	B	-	X	1%	870	2,320	2.5
Ventilation - room air temp. control (all-air systems) - variable capacity control (air flow or pressure control at the air handler level via automatic flow or pressure control with demand evaluation)	B	-	-	3%	2,980	5,320	2.0
Ventilation - room air temp. control (all-air systems) - demand control (sensors measuring indoor air parameters or adapted criteria (e.g. CO_2, mixed gas or VOC sensors))	B	-	X	4%	4,060	7,250	2.0

Table 21: Main results for all single measures of the reference office building (air heating)

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High performa nce package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
Proper dimensioning of pumps (space heating and cooling)	A	X	X	< 0.5%	350	-	0.0
Pipework of heating distribution system: Better insulation (accessible at non-heated zones, 100% of diameter)	A	X	-	< 0.5%	80	970	12.0
Pipework of heating distribution system: Better insulation (accessible at non-heated zones, 200% of diameter)	A	-	X	< 0.5%	140	1,080	7.5
Adjustment of pump volumes (automatic space heating and cooling)	A	X	X	1%	700	300	0.5
Adjustment of system temperatures (space heating and cooling)	A	X	X	< 0.5%	90	300	3.5
Adjustment of air volumes to actual demand	A	X	X	12%	5,530	2,800	0.5
Adjustment of heating and cooling supply (night/holiday/weekend switch-off)	A	X	X	2%	1,160	300	0.5
Heating: use weather compensation (supply/return temperature)	B	-	X	11%	3,270	8,030	2.5
Heating: optimum start/stop	B	-	-	17%	5,280	12,960	2.5
Heating - intermittent control of emission and/or distribution via automatic control with demand evaluation	B	-	-	25%	7,540	18,520	2.5
Heating - control of heat emitters provided by individual room control with communication	B	-	-	17%	5,280	12,960	2.5
Heating - control of heat emitters provided by individual room control with communication and presence detection	B	-	X	25%	7,540	27,780	3.5

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High performance package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
Lighting occupancy control	B	-	X	1%	1,080	1,930	2.0
Lighting daylight control	B	-	X	1%	1,080	1,930	2.0
Cooling - use of weather compensation (supply/return temperature)	B	-	X	1%	660	1,180	2.0
Cooling - optimum start/stop	B	-	X	1%	930	1,660	2.0
Cooling - control of emitters provided by individual room control with communication	B	-	-	2%	1,680	3,000	2.0
Cooling - control of emitters provided by individual room control with communication and presence detection	B	-	X	2%	2,480	6,640	2.5
Ventilation - room air temp. control (all-air systems) - variable capacity control (air flow or pressure control at the air handler level via automatic flow or pressure control with demand evaluation)	B	-	-	3%	2,980	5,320	2.0
Ventilation - room air temp. control (all-air systems) - demand control (sensors measuring indoor air parameters or adapted criteria (e.g. CO_2, mixed gas or VOC sensors))	B	-	X	4%	4,060	7,250	2.0

Table 22: Main results for all single measures of the reference supermarket (standard)

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High performance package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
Proper dimensioning of pumps (space heating and cooling)	A	X	X	< 0.5%	760	-	0.0
Pipework of heating distribution system: Better insulation (accessible at non-heated zones, 100% of diameter)	A	X	-	1%	690	1,810	2.5
Pipework of heating distribution system: Better insulation (accessible at non-heated zones, 200% of diameter)	A	-	X	2%	1,190	2,050	1.5
Adjustment of pump volumes (automatic space heating and cooling)	A	X	X	< 0.5%	940	300	0.5
Adjustment of system temperatures (space heating and cooling)	A	X	X	1%	150	300	2.0
Adjustment of air volumes to actual demand	A	X	X	8%	4,850	1,700	0.5
Adjustment of heating and cooling supply (night/holiday/weekend switch-off)	A	X	X	3%	1,900	300	0.0
Heating: use weather compensation (supply/return temperature)	B	-	-	16%	8,950	6,920	1.0
Heating: optimum start/stop	B	-	-	27%	15,260	11,810	1.0
Heating - pump management: variable speed/flow (delta p-variable)	B	-	X	< 0.5%	840	480	0.5
Heating - intermittent control of emission and/or distribution	B	-	X	51%	28,420	21,990	1.0
Lighting occupancy control	B	-	X	< 0.5%	720	1,040	1.5
Lighting daylight control	B	-	X	< 0.5%	720	1,040	1.5
Cooling - use of weather compensation (supply/return temperature)	B	-	-	< 0.5%	130	190	1.5

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High performance package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
Cooling - optimum start/stop	B	-	-	< 0.5%	90	120	1.5
Cooling - intermittent control of emission and/or distribution	B	-	X	< 0.5%	390	560	1.5
Ventilation - room air temp. control (all-air systems) - variable capacity control (air flow or pressure control at the air handler level via automatic flow or pressure control with demand evaluation)	B	-	-	1%	1,080	1,560	1.5
Ventilation - room air temp. control (all-air systems) - demand control (sensors measuring indoor air parameters or adapted criteria (e.g. CO_2, mixed gas or VOC sensors))	B	-	X	1%	1,370	1,980	1.5

Table 23: Main results for all single measures of the reference supermarket (advanced)

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High performance package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
Proper dimensioning of pumps (space heating and cooling)	A	X	X	< 0.5%	120	-	0.0
Pipework of heating distribution system: Better insulation (accessible at non-heated zones, 100% of diameter)	A	X	-	1%	100	1,810	18.0
Pipework of heating distribution system: Better insulation (accessible at non-heated zones, 200% of diameter)	A	-	X	2%	180	2,050	11.5
Adjustment of pump volumes (automatic space heating and cooling)	A	X	X	< 0.5%	170	300	2.0
Adjustment of system temperatures (space heating and cooling)	A	X	X	1%	60	300	5.0
Adjustment of air volumes to actual demand	A	X	X	8%	1,450	1,700	1.0
Adjustment of heating and cooling supply (night/holiday/weekend switch-off)	A	X	X	2%	280	300	1.0
Heating: use weather compensation (supply/return temperature)	B	-	-	12%	1,340	6,920	5.0
Heating: optimum start/stop	B	-	-	20%	2,280	11,810	5.0
Heating - pump management: variable speed/flow (delta p-variable)	B	-	X	< 0.5%	130	480	3.5
Heating - intermittent control of emission and/or distribution	B	-	X	38%	4,250	21,990	5.0
Lighting occupancy control	B	-	X	2%	720	1,040	1.5
Lighting daylight control	B	-	X	2%	720	1,040	1.5
Cooling - use of weather compensation (supply/return temperature)	B	-	-	< 0.5%	130	190	1.5

Optimisation measure	Calculation method A = DIN V 18599 B = EN 15232/ EN 15316	Get the basic right package	High performance package	Final energy savings [%]	Energy cost savings [Euro]	Invest-ment [Euro]	Payback period [years]
Cooling - optimum start/stop	B	-	-	< 0.5%	90	120	1.5
Cooling - intermittent control of emission and/or distribution	B	-	X	1%	390	560	1.5
Ventilation - room air temp. control (all-air systems) - variable capacity control (air flow or pressure control at the air handler level via automatic flow or pressure control with demand evaluation)	B	-	-	3%	1,080	1,560	1.5
Ventilation - room air temp. control (all-air systems) - demand control (sensors measuring indoor air parameters or adapted criteria (e.g. CO_2, mixed gas or VOC sensors))	B	-	-	4%	1,370	1,980	1.5
Ventilation - heat recovery control (prevention of overheating and icing protection)	B	-	X	5%	1,890	2,730	1.5

6.2.4 Savings potential of optimisation packages

Table 24: Main results for packages of all reference buildings

Reference building[71]	Packages	Final energy savings [%]	Energy cost savings[72] [Euro]	Investment [Euro]	Payback period [years]
Single-family house [180 kWh/m²a]	Get the basics right	21%	390	1,400	3.5
	High performance	33%	630	3,700	6.0
Multi-family house (Gas) [156 kWh/m²a]	Get the basics right	28%	10,330	14,110	1.5
	High performance	40%	14,660	63,840	4.5
Multi-family house (District heating) [156 kWh/m²a]	Get the basics right	29%	16,520	14,110	1.0
	High performance	40%	23,320	63,840	2.5
Multi-family house (Heat pump) [66 kWh/m²a]	Get the basics right	34%	19,140	14,110	0.5
	High performance	46%	25,780	69,280	2.5
Office (Radiators) [297 kWh/m²a]	Get the basics right	20%	7,970	7,150	1.0
	High performance	41%	18,560	78,350	4.0
Office (Air heating) [302 kWh/m²a]	Get the basics right	18%	8,600	5,170	0.5
	High performance	44%	21,220	64,800	3.0
Supermarket (Standard) [894 kWh/m²a][73]	Get the basics right	16%	10,610	4,910	0.5
	High performance	49%	30,700	35,360	1.0
Supermarket (Advanced) [181 kWh/m²a]	Get the basics right	14%	2,370	4,910	2.0
	High performance	45%	8,080	36,110	4.5

[71] Including space heating, domestic hot water and auxiliary energy for residential buildings, and additionally ventilation, space cooling and lighting in non-residential buildings.
[72] EU28 energy cost averages from 2017 to 2030 as used in EPBD impact assessment (Gas: 5.9 ct/kWh; District heat: 9.6 ct/kWh; Electricity: 21.9 ct/kWh). For further explanations see footnote 55.
[73] Space heating demand with heat recovery down to 20%; Investment for heat recovery around 23,550 EUR, according to Danfoss 2017.

6.3 Annex 3 - Factsheets

The following cases will be presented in separate factsheets:

- **Single-family house**
- **Multi-family house**
- **Office building**
- **Standard supermarket**
- **Advanced supermarket**

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