Optimizing the control of energy use in technical building systems – why energy and climate policies should fill regulatory gaps

Helge Schramm
Danfoss A/S
Nordborgvej 81
6430 Nordborg
Denmark
helge.schramm@danfoss.com

Matjaž Osojnik, BScM
Danfoss Trata d.o.o.
Jožeta Jame 16
SI-1210 Ljubljana
Slovenia
matjaz.osojnik@danfoss.com

Jepser Therbo
Global Director HVAC, BSc
Danfoss Drives A/S
Ulsnaes 1
6300 Graasten
Denmark
jesper.therbo@danfoss.com

Stephan Kolb, Ph.D.
Danfoss N.V./S.A.
Rue Jacques de Lalaing 4
1040 Bruxelles
Belgium
stephan.kolb@danfoss.com

Alix Chambris
Danfoss N.V./S.A.
Rue Jacques de Lalaing 4
1040 Bruxelles
Belgium
chambris@danfoss.com

Torben Funder-Kristensen, Ph.D.
Danfoss A/S
Nordborgvej 81
6430 Nordborg
Denmark
tfk@danfoss.com

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Abstract
This paper presents an analysis of the role of improving technical building systems (TBS) for space heating, domestic hot water, air-conditioning and ventilation for the energy and climate objectives of the EU. The scope of the analysis is optimizing system performance by control of energy generation, distribution and emission of heating and cooling energy in residential and non-residential buildings. It considers technologies that "get the basics right", and achieve "high performance" both from a hydraulic and a connected ICT perspective. First, the paper summarizes the results of new, independent research on EU aggregated GHG emission and primary energy saving potentials. Then, the paper explains key functionalities, benefits and added-value of existing technologies, and shows that energy efficient technical building systems is a very attractive investment case. The third part illustrates barriers that impede investments in technical building systems. Finally, as an input to the on-going revision of the EU energy efficiency acquis, the paper recommends policy measures that would overcome typical barriers for investments into upgrade of technical building systems, and assesses the interaction between investment into technical building systems and thermal upgrade of the buildings envelope, on the path towards the EU's 2050 GHG reduction objectives.

Introduction
In Europe's residential and non-residential building stock, 75 % of total final energy consumption in 2013 (see Figure 1) was used for space and water heating alone [1]. This energy consumption is the result of two elements: (i) heat demand, which can be influenced by insulation measures, and (ii) technical building systems, which can be influenced by control of energy generation, distribution and emission and by the heat generator. This paper focuses on the technical building systems except for the heat generator[1].

According to Art. 8 of the Energy Performance of Buildings Directive 2010/31/EU (hereafter EPBD) Member States shall, for the purpose of optimizing 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. The system requirements must cover at least (a) heating systems; (b) hot water systems; (c) air-conditioning systems; (d) ventilation systems, or a combination of such systems.

The objectives of the provision are to minimize energy use of technical building systems by proper installation, adjustment and control and thus to reduce energy use in buildings. It applies to both new and existing buildings.

A new research shows, that there is a lack of guidance on how to interpret and implement Art. 8 EPBD. This paper argues that one way to enforce the existing provision will be to simplify the enforcement by adopting requirements on functionalities (like

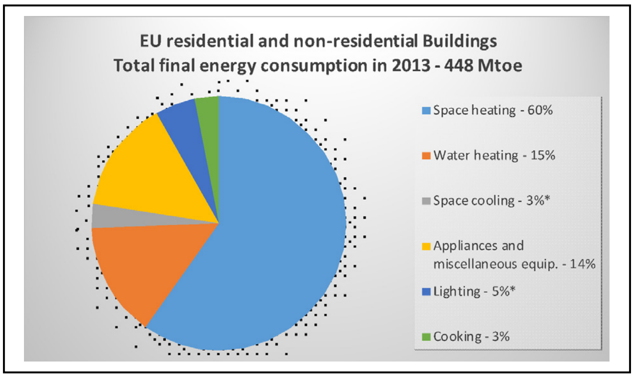
1. The analysis does not include the exchange of the heat generator, but it includes the optimization of the control of energy generation

control of energy generation, distribution and emission of heating, cooling and ventilation) [3].

With 36 % natural gas represents the highest share of total final energy consumption in buildings [1]. CO_2 emissions from space and water heating are responsible for 94 % of the total emissions by end-use in 2013 (see Figure 1 and 2). This makes investments that can reduce the demand for space, hot water, ventilation and cooling critical for the achievement of the EU energy and climate goals, especially for buildings heated by gas which will remain the case for the majority of the EU building stock in the near future.

At EU level, the average annual specific consumption per m² for all types of residential buildings (in total app. 19,6 billion m²) was around 180 kWh/m² in 2013, while non-residential buildings (in total app. 6,9 billion m²) are on average 40 % more energy intensive than residential buildings (250 kWh/m² compared to 180 kWh/m²) [2].

As there is currently a lack of trust and lack of data on savings potential from the optimization of technical building systems, a new, independent research on EU aggregated GHG emission and primary energy saving potentials has been initiated[2]. The study presents a systematic analysis of technologies that optimize technical building systems installed in Europe's building stock, and quantifies the benefits of upgrading such systems to two scenarios in eight different reference cases, representing typical European situations for energy supply and envelope characteristics in Europe's buildings. The savings of the eight reference cases are then extrapolated at EU 28 level. It shows the effects of fast and addressable improvements based on existing technologies and combinations of systems across the EU assuming that 3.6 % of Technical Building Systems are upgraded per year. This corresponds to the annual renovation rate of heat generators (mostly boilers), meaning that by 2030, half of the existing buildings would have optimized their technical building systems[3].



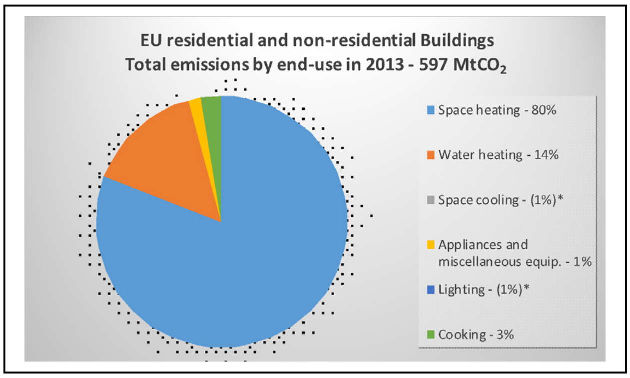


*Figure 1 and 2. EU residential and non-residential Buildings – Total final energy consumption and emissions by end-use [1]; *variation between 1 to 5 %.*

Methodology

The results shared within this technical paper are based on two methodologies.

The first methodology analyzes the savings that can be achieved by optimization of existing building systems in different types of buildings. In a first step, eight reference buildings (four residential and four non-residential) with their respective heating, cooling, hot water, ventilation and lighting specifications are defined. Then, optimization measures and packages regarding the aspects mentioned within Art. 8 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). 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 savings shared within this technical paper, do not include any savings linked to an exchange of the heat generator. The energy demand calculation for each reference case and every measure took into account national climate data and normative reference calculation parameters according to EN 15232 and EN 15316 for the EPBD aspect automation, control and monitoring systems and DIN V 18599 for the aspects appropriate dimensioning, proper installation, and adjustment. The DIN V 18599 ensures the CEN-EPBD conformity.

The second methodology estimate an order of magnitude of CO_2 emissions and primary energy reductions that would result from aggregating the reductions calculated for the optimization of technical building systems of the reference buildings to the EU level. The effects on EU level in 2030, including investment costs and the energy cost savings, are calculated for two different scenarios ("get the basics right", and "high performance"). The get the basics right package for residential buildings includes 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), adjustments (such as night setbacks for space heating and hot water) and control (automatic hydronic balancing and installation of modern thermostatic valves). Further automation, control and monitoring systems are not included in the package. The high-performance package for residential buildings include measures of the get the basic right package regarding appropriate dimensioning, proper installation (with even better insulation levels) and adjustments. Automation, control and monitoring systems are included in the high-performance package (e.g. boiler use weather compensation, pump optimization, and the

2. ECOFYS, 2017 [3].
3. ECOFYS, 2017 [3].

installation of electronic thermostatic radiator valves). The get the basics right package for non-residential buildings 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), adjustments (such as air volume adjustment to actual demand). The high-performance package for non-residential buildings includes measures of the get the basic right package regarding appropriate dimensioning, proper installation (with even better insulation levels) and 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)). After definition of scenarios on the basis of the optimization packages (step 1), the second step takes all reference buildings and allocates the whole European building stock to these 8 types using extrapolation. The application of the two different scenarios 1) get the basics right package and 2) high performance takes place. The reference buildings used represent a simplified model of the European building stock. The German building stock has been considered with the assumption, that it can be a good proxy for a building stock situated in a moderate climate zone. In the light of a rather conservative approach, the implementation rate equal to the EU average of the exchange of heating systems being about 3.6 % (step 3 – trigger moment). Therefore, the total implementation of the packages in 2030 within the building stock is assumed to be approx. 47 % over the 13-year period. Finally, the effects until 2030 on EU level are calculated [3].

Results

As an output the new, independent research summarizes aggregated CO_2 emission and primary energy saving potential that can be achieved in addition to a Business as Usual pathway, as well as the total investments needed and the achievable energy cost savings (each per year) for the two scenarios [3]. See Table 1[4].

With cumulated net savings of EUR 150 bln[5], considering the average annual cumulated energy cost savings over 2017–2030 minus investment costs, and assuming that 3.6 % of TBS per year are upgraded to the high performance scenario, which equals 46.8 % of the market until 2030, the investment in energy efficient technical building systems is very attractive [3]. From the environmental perspective, the investment result in app. 882 $MtCO_2$ cumulated emission reductions until 2030.

In order to consider that a part of the get the basics right measures will be implemented anyway (expert assumption: 1/3 of the get the basic right savings due to legal and economic context), the following figure shows the additional CO_2 emission reduction in the two scenarios and the effect of the Business as usual (BAU) (savings that happen anyway including savings due to ongoing de-carbonization of district heat and power and energy reduction assumptions) [3].

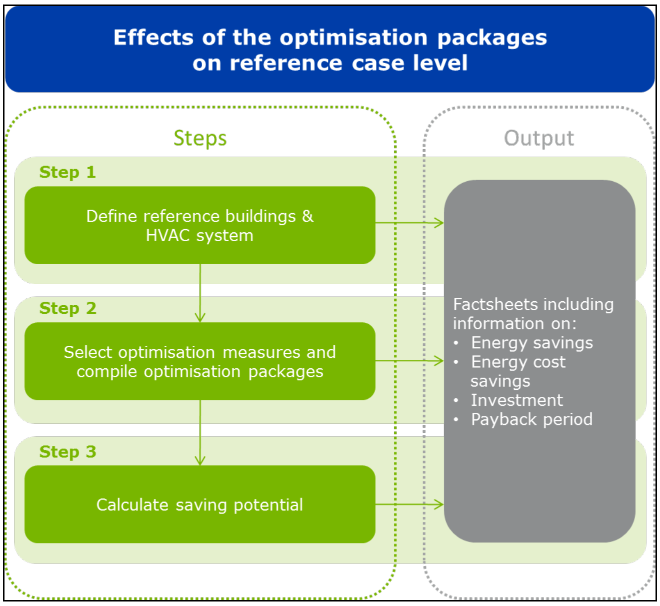


Figure 3. First methodology – effects of the optimization packages on reference case level [3].

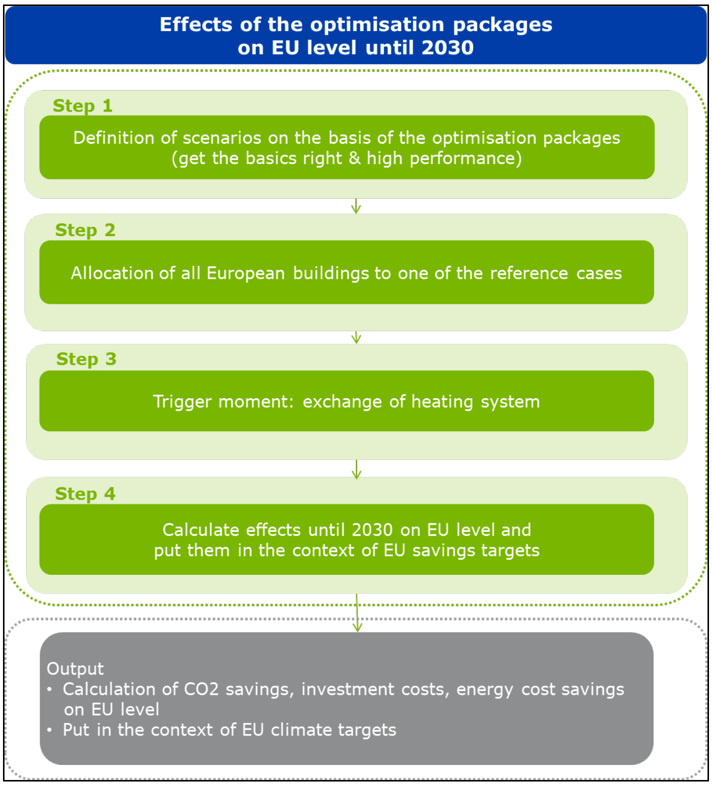


Figure 4. Second methodology – effects of the optimization packages on EU level until 2030 [3].

4. Investment cost per year: E.g. the EUR 5.2 bln 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.

5. EU 28 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).

Table 1. Overview results [3].

	Impact on CO_2 emission reduction in 2030[3] [$MtCO_2$]	Impact on primary energy reduction in 2030[3] [Mtoe]	Energy cost savings per year [bln EUR / year]	Investment cost per year [bln EUR / year]	Payback [years]
Get the basics right[1]	61	27	2.8	5.6	2.0
High performance[1, 2]	126	58	5.2	24.8	4.8

[1] not considering the BAU scenario with an impact of 30 $MtCO_2$ and 13 Mtoe in 2030; [2] incl. the impact of get the basics right; [3] optimized TBS implemented in 47 % of the EU building stock until 2030.

Also, the DIN V 18599 has been chosen, which applies a static simulation on a monthly basis, the calculated results show, that the saving potential of the optimization packages are significant and – on the level of individual reference cases (depending on the building and control technology) – are in a range from 14 % to 49 %[6] with an average of about 30 % savings of final energy [3]. The "get the basic right" scenario includes no-regret measures with low investment and short payback period. The "high-performance" scenario includes a set of advanced measures (mainly building automation and control systems) leading to a total reduction of 156 $MtCO_2$ emissions per year in 2030 [3].

Key benefits and added-value of efficient control functionalities

This chapter explains fundamental parts and functionalities of technical building systems, like room temperature control (e.g. by individual room control with thermostatic radiator valves), control of water temperature distribution (e.g. by automatic hydronic/thermal balancing), control of generation (e.g. by variable speed drive controlled compressors), air flow control (e.g. by variable demand control) and heat recovery from commercial refrigeration systems. By using the findings of different studies, like [3], [4], [20], and on-site investments and measurements [8] the benefits and energy savings that can be harvested by efficient control functionalities are estimated.

SPACE HEATING: ROOM TEMPERATURE CONTROL AND CONTROL OF WATER TEMPERATURE DISTRIBUTION

More than 500 mln radiators in actual use in Europe's homes are still fitted with simple radiator valves (SRV) – that means the temperature is not kept at the desired level, and energy is squandered e.g. due to overheating. A complete replacement of all simple radiator valves in residential buildings could lead to final energy savings of **14.4 Mtoe** per year for the citizens. This corresponds to annual emissions savings of about **31 $MtCO_2$**, and energy cost savings in residential buildings of about **EUR 9.9 bln**, with an average payback period of **2.5 years**. A radiator thermostat is designed to automatically feed the right amount of heated water into a radiator, which is needed to efficiently bring a room to the desired temperature. Many residents are unfamiliar with the operation of a radiator thermostat and the conditions in which it performs best. Providing the right information to the residents and choosing the right type of thermostatic sensor for the situation is often underestimated [7]. App. EUR 2 per m² and year can be saved on average on energy costs within the European residential building stock, due to change from simple to thermostatic radiator valves (TRV) (considering natural gas as energy source).

While the efficiency of new buildings has improved over time, most of Europe's existing building stock – over 90 % of the total – has yet to be affected by energy performance requirements [5], e.g. have "unbalanced" or poorly balanced heating systems. For multifamily buildings, this means that some apartments are overheated, while others remain too cold. Unbalanced or not properly balanced systems result in high flows through their pipes. In many cases this applies to situations where the flow through the pipes and radiator control valves is so turbulent that it causes a rushing sound. Besides the fact that residents will complain about the noise, turbulent flow causes unnecessary loss of heat and pressure [7]. Optimizing the space heating system within residential buildings, by implementing automatic balancing of the risers or flats with differential pressure controllers, could save 8 % of the average annual specific energy consumption. This could lead to final energy savings of **6.8 Mtoe** per year for the citizens, which corresponds to annual emissions savings of about **15.9 $MtCO_2$**, and energy cost savings of about **EUR 6 bln**, with an average payback period of **2 years**.

DOMESTIC HOT WATER: CONTROL OF WATER TEMPERATURE DISTRIBUTION

Gas fired water heaters account for over half of all the energy consumed for the production of DHW [2]. By implementing automatic thermal balancing control at DHW circulation lines, within residential buildings, the DHW system is optimized, and could save 4 % of the average annual specific energy consumption. This could lead to final energy savings of **3.4 Mtoe** per year for the citizens, which corresponds to annual emissions savings of about **8 $MtCO_2$**, and energy cost savings of about **EUR 3.5 bln**, with an average payback period of **2 years**. For distribution of domestic hot water, there are two basic configurations used: (i) centralized distribution and (ii) decentralized distribution. Centralized distribution is most used in existing stock of buildings. In such systems, hot water is prepared centrally in substation and stored in central tank, from which domestic hot water is distributed to end user. To keep water hot and to prevent long waiting times, additional circulation pipes are used, which are designed to keep water flow in the pipes.

6. These savings are achieved by optimizing whole systems which already have new heat generators, but where the operation and settings of the heat generator have not yet been optimized.

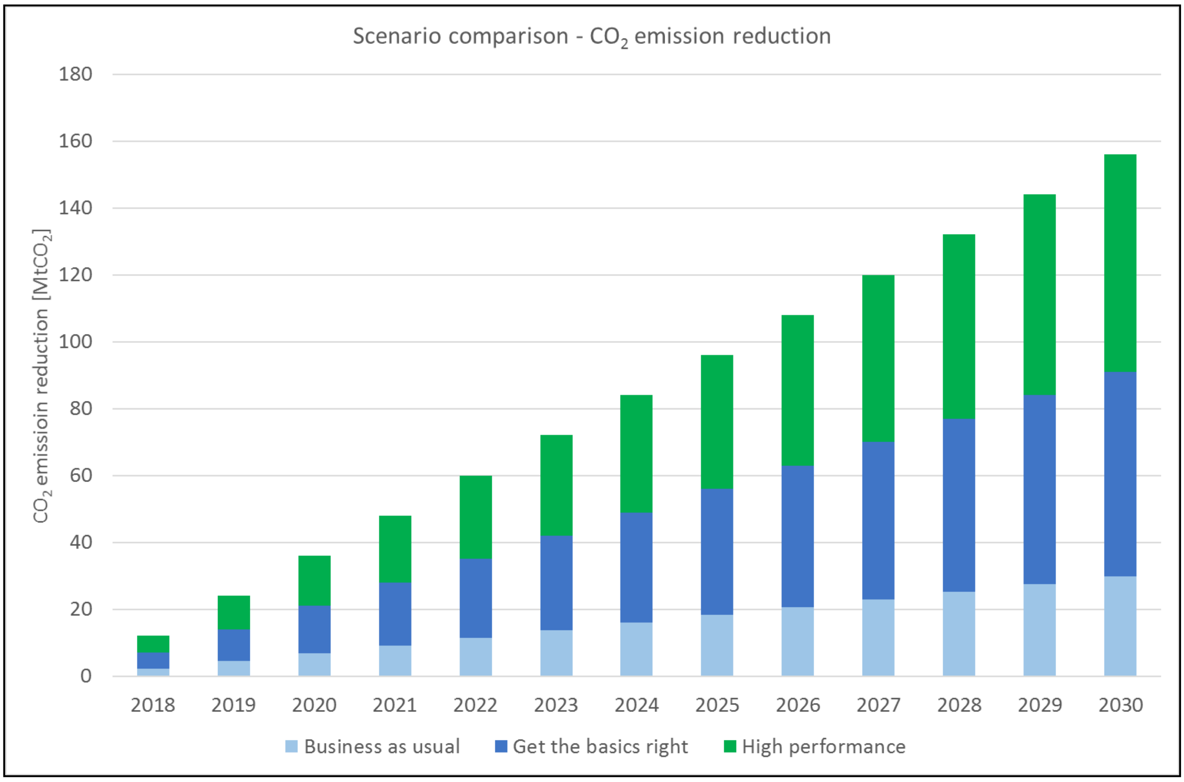


Figure 5. Scenario comparison; max. potential CO_2 emission reductions by TBS scenarios; $MtCO_2$ per year.

Table 2. Key parameters used for the environmental and economic assessment [3].

	Energy price – Non-residential and residential buildings [ct/kWh] (without VAT)	CO_2 emission factor for 2017 [gCO_2/kWh]	CO_2 emission factor for 2030 [gCO_2/kWh]
Natural gas	5.9	202	202
Electricity	21.9	327	204

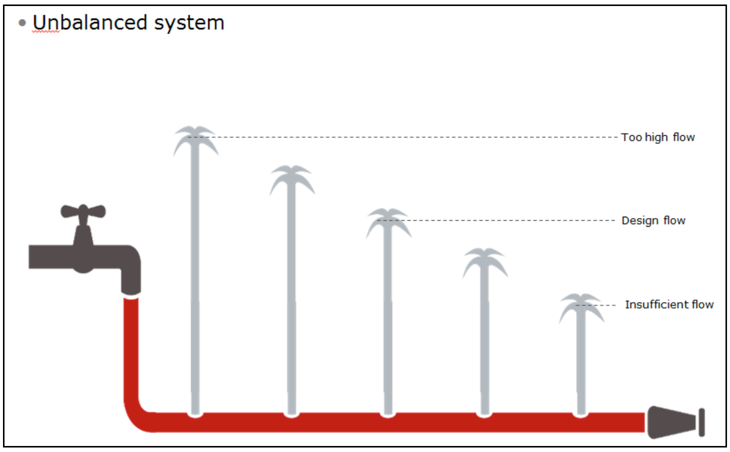


Figure 6. Unbalanced systems cause uneven distribution of water [7].

In the circulation loops close to the pump (represented above with a water tap) the water flow can be several times higher as necessary for proper functioning. The consequence of this is that the pressure loss in pipes increases dramatically which results in too little pressure being available for the 'critical' loops which are furthest away from the boiler room. Because of this circulation water temperature in those loops is lower than needed. So, common consequence is that end user opens the tap and then waits a long time till circulating hot water is replaced by hot water from the tank. Waiting time can be as long as a minute which results in big amount of wasted water.

Automatic thermal balanced DHW systems ensure the correct flow in the loop to cover the heat loses, resulting in right water temperature circulating throughout whole system at minimum temperatures and water flows. The solution is independent from the distance from storage tank and temporary hot water usage. Thus, quantity of circulation water during all periods is significantly reduced. The implementation of automatic thermal balancing in DHW systems can reduce the final energy consumption for DHW by up to 16 % with an investment payback time of less than one year [8].

AIR-CONDITIONING: CONTROL OF ENERGY GENERATION, DISTRIBUTION AND EMISSION

Space cooling uses in average less than 1 % of total residential energy consumption in Europe, but for countries with warm weather, like Bulgaria, Cyprus and Italy, it represents up to 5 % of total residential consumption (even 12 % in Malta) [2]. Within non-residential buildings space cooling accounted for 19 % of the total final energy consumption in 2012 [14]. Assuming that today 50 % of the total non-residential building stock operates fixed speed systems, the implementation of Variable Speed Drive (VSD) controlled could lead to final energy savings of **2.1 Mtoe** per year, which corresponds to annual emissions savings of about **5 MtCO$_2$**, and energy cost savings of about **EUR 5.9 bln**, with an average payback period below **1.5 years**.

Chillers in air-condition systems typically operate the majority of the time at part-load conditions. Therefore, VSD controlled compressors provide significant energy savings. In existing buildings, large energy savings are possible, if the existing chiller is fitted with a VSD, so that the compressor capacity is accurately adapted to the actual need. The benefits obtained are typically:

- Substantial Energy Savings
- Better asset protection
- Fewer start/stop and peak loads on the electrical grid
- Less maintenance cost
- Higher plant reliability/performance

Depending on the load cycle, energy savings will typically range from 10–30 %, compared to the amount of electricity used by traditional, fixed speed systems, and the payback will in most cases be below one year. The implementation of further functionalities like automatic balancing (pressure independent balancing and control) and individual room control within non-residential buildings could lead to additional savings of **4.5 Mtoe** per year, which corresponds to annual emissions savings of about **10 MtCO$_2$**, and energy cost savings of about **EUR 4.5 bln**, with an average payback period below **2.5 years**.

VENTILATION: AIR FLOW CONTROL

Large parts of mechanical ventilation systems in the existing building stock are running at fixed speed, and featuring low efficient belt-driven fans and low efficient motors. Optimizing the ventilation system within non-residential buildings, by implementing ventilation with variable demand control, could save 4 % of the average annual specific energy consumption of 250 kWh/m². This could lead to final energy savings of **4 Mtoe** per year, which corresponds to annual emissions savings of about **9.5 MtCO$_2$**, and energy cost savings of about **EUR 13.5 bln**, with an average payback period of **1.5 years**. The considerable daily load variation makes it economically attractive to install VSD on more or less all rotating equipment such as pumps and fans. Thereby it is possible to adapt the capacity of the ventilation system to the actual requirement in the building, over the day, week and year. As an example, just 20 % reduction in fan/pump speed can offer app. 45 % energy savings, compared to the amount of electricity used by traditional, fixed speed systems. In addition to installing VSD's on the fans, it will provide a large additional energy saving, if the old in-efficient belt driven fan and motor are replaced with a new high efficient direct drive fan and high efficient motor. Energy consumption will in most cases be reduced with additional 25–40 %. The benefits obtained are similar to the points mentioned above under air-conditioning.

HEAT RECOVERY FROM COMMERCIAL REFRIGERATION SYSTEMS

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 [11]. Cooling technology in supermarket applications is of great energetic and economic importance. In Germany about 1.4 % of the electrical energy consumption is used for refrigeration in supermarket application [15]. If supermarkets utilized the surplus heat from the CO$_2$ refrigeration units to heat the space and domestic hot water within their own building, this could lead to final energy savings of **2.6 Mtoe** per year, which corresponds to annual emissions savings **6.1 MtCO$_2$**, and energy cost savings of **EUR 1.8 bln**, with an average payback period of **1.5 years**.

In a larger scale perspective, connecting supermarkets to external thermal networks and utilizing the fluctuating renewable electricity can provide a large heat contribution. Germany has a food retail outlet area of 30 million m². Assuming this area to represent an equivalent opportunity to export to the District Heating (DH) grid, around 0.5 Mtoe of heat could be delivered – just based on the surplus heat itself [10]. See Tables 3–5[7].

7. Estimates based on findings within different studies and onsite investment and measurements.

Table 3. Overview of key functionalities and added-value – Residential buildings.

TBS	Key functionalities	Core element	Added-value Reduced energy consumption	Added-value Energy cost savings
Space heating	Room temperature control	Thermostatic radiator valve	**From 24.6 Mtoe** (based on a static simulation on a monthly basis – DIN V 18599) **up to 37.2 Mtoe** (based on a dynamic simulation/thermal behaviour – TRNSYS)	**From EUR 19.4 bln** (considering static simulation on a monthly basis – DIN V 18599) **up to EUR 28.3 bln** (considering dynamic simulation/thermal behaviour – TRNSYS)
Space heating	Control of water/temperature distribution	Automatic hydronic balancing valve		
Domestic hot water	Control of water/temperature distribution	Automatic thermal balancing valve		

Table 4. Overview of key functionalities and added-value – Non-Residential buildings.

TBS	Key functionalities	Core element	Added-value Reduced energy consumption	Added-value Energy cost savings
Air conditioning	Control of energy generation	Variable speed drive controlled compressors	**10.6 Mtoe** (based on a static simulation on a monthly basis – DIN V 18599)	**EUR 23.9 bln** (considering static simulation on a monthly basis – DIN V 18599)
Air conditioning	Control of energy distribution/emission	Pressure independent balancing and control valve		
Air flow control	Air flow control	Variable speed drive controlled fan		

Table 5. Key parameters used for the added-value evaluation of efficient control functionalities.

	Floor area	% of total EU residential/non-residential floor area	Final energy saving potential	Energy cost savings potential
Room temperature control	5.14 bln m² (residential)	26.2 % (residential)	13–19 %[1] (up to 36 %[2, 3])	EUR 1.93/m²a
Control of water/temperature distribution (space heating)	6.35 bln m² (residential)	32.4 % (residential)	8 % up to (15 %[3, 4])	0.96 EUR/m²a up to (EUR 1.73/m²a)[3, 4]
Control of water/temperature distribution (domestic hot water)	6.35 bln m² (residential)	32.4 % (residential)	4 %	EUR 0.49/m²a
Control of energy generation (Air conditioning)	2.59 bln m² (non-residential)	37.5 % (non-residential)	6 %	EUR 2.28/m²a
Control of energy distribution/emission (Air conditioning)	2.59 bln m² (non-residential)	37.5 % (non-residential)	8 % up to (25 %)[5, 3]	EUR 1.73/m²a up to (EUR 4.97/m²a)[5, 3]
Air flow control	4.66 bln m² (non-residential)	67.5 % (non-residential)	4 %	EUR 2.91/m²a

[1] Changing SRV to TRV, incl. 50 % manual balancing [4]; [2] exchange SRV and operation mode/dynamic simulation [20]; [3] not considered for added-value evaluation within Tables 3 and 4; [4] dynamic balancing avoiding system temperature increase; [5] e.g. by intermittent control of distribution/emission via automatic control with demand evaluation.

Barriers that impede investments in technical building systems

There is a significant energy (app. 35.2 Mtoe), economic (app. EUR 43.3 bln) and environmental (app. 80 $MtCO_2$) saving potential with payback periods below 2.5 years, considering only the key functionalities based on static simulation mentioned in Tables 3 and 4 (without heat recovery), by optimizing the control of energy generation, distribution and emission in technical building systems.

Nevertheless, the profitability and environmental benefit of measures does not translate into the reality of actually taking these actions due to persistence of barriers to energy efficiency.

The new 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'".

There is a lack of guidance on how to interpret Art. 8 EPBD and how to define system performance. This leads to uncertainty about how to apply it on the national level and thus results in an only modest impact of Art. 8 on building energy performance. Different sources reveal that 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.

Beside standards like the EN 15232 and EN 15316 for the EPBD aspect automation, control and monitoring systems and DIN V 18599 for the aspects appropriate dimensioning, proper installation, and adjustment, there is still no common understanding about how to calculate the savings that optimized technical building systems can deliver. While working on this project there have been many discussions with experts, reviewed literature and plenty of calculations using certified software with the objective to determine the actual saving potential of optimizing technical building systems. Right now, current standards which applies a static simulation on a monthly basis, like DIN V 18599, are not capable to evaluate the real saving potential on technical building system level (e.g. effective controls for generation, distribution, and emission at full and partial demand loads to match energy use to building and occupant needs). On the other side, it is quite difficult to use studies or results of real cases, as they do not exactly state the baseline and all parameters which determine the buildings' energy consumption.

In addition, it is important to reflect on and cover both actual and designed heat use. After finalizing construction or renovation, elements are adjusted to achieve the desired comfort level of buildings, for example turning on the heating/thermostat when cold, opening the window for ventilation, turning on the air-conditioning if too warm, switch on the lights, etc. Very often, this behavior leads to the fact that the calculated final energy demand and the real-measured final energy demand being very different [19]. Technical building systems, like room temperature control, dynamic balancing[8], or automatic control with demand evaluation, could help to mitigate the mismatch and ensure a high actual energy performance of the building.

Around 70 % of the EU population lives in privately owned residential buildings. Owners often do not undertake cost-efficient renovations, because they lack awareness of the benefits, lack advice on the technical possibilities, and have financing constraints [14].

In privately-owned rented buildings – a large share in some countries – the main challenges are split incentives, tenancy rules and finance. Incentives are "split" in the sense that property owners have little incentive to invest, if the tenant pays the energy bill.

There is no coherent legislation, and no clear understanding of policy makers at national level about the impact of e.g. room control and hydronic balancing. In France legislation require balancing, but not automatic balancing, while in Spain is no obligation to install TRV's in all rooms (only in dry rooms).

Policy recommendations

Existing buildings regulations should be fully implemented, harmonized and consistently enforced across EU Member States. Future regulatory pathways for EU buildings should provide concerted and consistent regulatory framework to improve the energy efficiency of buildings [13].

One way to enforce the existing provision will be to simplify the enforcement by adopting requirements on functionalities (like control of energy generation, distribution and emission for heating, cooling and ventilation), and to accelerate the optimization of TBS beyond the heat generator issue. The adoption should combine push and pull elements. Binding requirements on control functionalities mentioned in Table 3 and 4 with application dates, and smart readiness indicators like building performance [19], which enhance the ability of occupants and the building itself to react to comfort of operational requirements, take part in demand response and contribute to the optimum, smooth and safe operation of the various energy systems and district infrastructure to which the building is connected [18]. Requirements should target both the residential and non-residential existing building stock. Residential buildings account for 60 % to 90 % of the floor area, depending on the Member State, and their main energy cost driver is heating. Therefore, any policy that tackles the current shortcomings must keep residential buildings in focus. This should be seen as a no-regret, as the renovation has relatively low investment costs and short payback times which should drive full exploitation of the savings potential.

It is necessary to include the optimization of technical building systems in national renovation strategies. The implementation of TBS with payback periods below 2.5 years, financially support the long term thermal upgrade of the European buildings envelope on the path towards the EU's 2050 GHG reduction objectives.

Beside the cumulated net savings of EUR 150 bln until 2030, the optimization of technical building systems results in 882 $MtCO_2$ cumulated emission reduction until 2030.

8. Both terminologies are used e.g. dynamic balancing, and automatic balancing / automatic hydronic balancing.

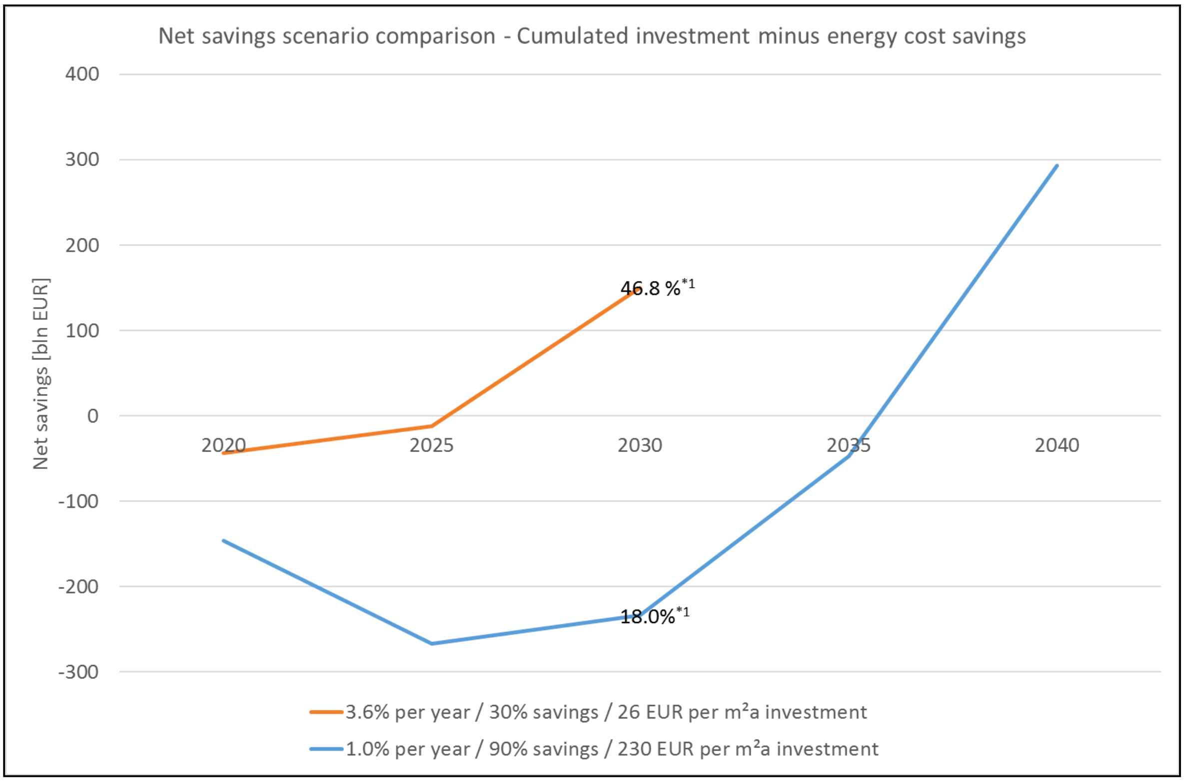


Figure 7. Net savings scenario comparison; [1] of the EU building stock renovated.

Comparing this to an extensive renovation scenario [21] leading to energy reduction of 90 % *(in Figure 7: "1.0 per year/% savings/EUR 230*[9] *per m²a investment"-scenario)* with cumulated "net savings" of minus EUR 233 bln and cumulated emission reduction of 805 $MtCO_2$ until 2030, the economic and environmental power of unleashing Art. 8 EPBD is obvious.

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 suffice. 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 [3]. 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.

9. Extensive renovations with average cost of EUR 230/m² [21], not considered energy price and technology price differentiation (payback time 10 years) (to visualize, that there is no-lock-in effect).

In addition, recommendations on heat recovery, e.g. for supermarkets, and other non-residential buildings, should be considered within Art. 8 EPBD, as there is a huge, additional energy saving potential.

The mechanism to track and trace progress via collection of data at national level on the state of TBS/functionalities in the existing building stock beyond the heat generator issue (e.g. via European buildings observatory) is necessary.

Conclusion

Buildings are responsible for the largest share of European final energy consumption (40 %) and they represent the greatest potential to save energy – as 75 % of buildings standing in the EU were built during periods with no, or minimal, energy-related building codes and the energy intensity of heating per floor area is two times higher than any other region of the world (except Russia). Buildings are long-term assets expected to remain in use for 50 or more years and 75–90 % of those standing today are expected to remain in use in 2050 [13]. Considering these facts, the optimization of the technical building systems (not taking into account savings achievable from the replacement of heat generators), which leads to average energy savings of 30 %, is a key enabler to fulfil the EU's climate and energy goals. As Energy Efficiency investment is strategically important for the European Union, it is the most cost effective manner to reduce the EU's reliance, and expenditure, on energy imports costing over EUR 400 bln a year [13], only by implementing the key functionalities mentioned in the chapter above (without heat recovery), this energy import cost could be reduced by app. 4 %.

The IEA, in its 450 scenarios, sees the EU as needing to invest a further EUR 59 bln per year until 2035 in energy efficiency in buildings, which means almost doubling current investment trends [13]. 28 % of this further EE investment need could just come from the net savings per year by optimizing the energy use of technical building systems mentioned above. Considering the payback periods around 2.5 years, this will be a key enabler on the path towards the EU's 2050 GHG reduction objectives, as it financially supports the long term thermal upgrade of the existing, European buildings envelope, while ensuring indoor air quality and thermal comfort.

Optimization of technical building systems can deliver quick savings without running into lock-in-effects. This reduces cumulated emissions. Therefore, the speed of optimization needs to increase. In the new study, it was assumed that renovation rates of technical building systems could be in the range of 3–4 %, which is similar to current heat exchanger rate. This is approximately three times the current renovation rate of buildings, and key to not "waste" savings potentials and locking them in until the next renovation cycle. Quick savings with relatively low investment costs and short payback times do not create lock-in effects, and significantly help to reduce cumulated emissions which are the key drivers for climate change.

Although the new study deals with the savings potential of technical building systems, saving strategies need to focus on synergies between different technologies, aiming at the building's comfort and efficiency (envelope, building system), the interplay with on-site renewables and on managing the building's usefulness within the overall energy system (district energy). 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 [3].

In addition, compared to actual new building practice, nearly zero energy buildings (nZEB's) require a well mastered equilibrium between minimized energy losses, internal gains and the remaining energy needs. In most cases control systems, e.g. balanced ventilation systems with heat recovery, will be necessary to reach this equilibrium [6].

A fully implemented, harmonized and consistently enforced Art. 8 EPBD has the potential to reduce the total CO_2 emissions (figure 2 – Residential and non-residential buildings total CO_2 emissions of 597 $MtCO_2$ in 2013) by at least 26 % until 2030. This order of magnitude is conservative, as the results within figure 5 only considers the implementation in half of the EU building stock until 2030. Considering in addition 115 $MtCO_2$ in 2030 (assumption) from the "1 %/90 % savings/EUR 230 per m²a investment" scenario, there is a total reduction potential of 45 %.

Regardless of a common understanding about the exact range of savings, technical building systems clearly have a significant savings potential. Regarding current European climate targets and a prospective tightening in the light of the Paris agreement, it is obvious that all available measures will be needed to meet the target. Thus, in any case it is ecologically and economically worthwhile to push for full exploitation of Article 8's saving potential.

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