IS EUROPE READY FOR THE SMART BUILDINGS REVOLUTION?

MAPPING SMART-READINESS AND INNOVATIVE CASE STUDIES

BPIE

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BPIE would like to acknowledge the contribution to this paper, through challenging feedback and constructive criticism, by the following experts:
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Alix Chambris, Danfoss
Jonna Byskata, United Technologies Corporation
Patty Fong, European Climate Foundation
Frauke Thies, Smart Energy Demand Coalition

BPIE would like to thank the European Climate Foundation and Danfoss for the financial support for this project.

Published in February 2017 by the Buildings Performance Institute Europe (BPIE).

The Buildings Performance Institute Europe is a European not-for-profit think-tank with a focus on independent analysis and knowledge dissemination, supporting evidence-based policy making in the field of energy performance in buildings. It delivers policy analysis, policy advice and implementation support.
www.bpie.eu

ISBN: 9789491143182

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INTRODUCTION

The European building stock and energy system are at the initial stages of a journey towards becoming smart: moving from a centralised, fossil fuel-based and highly-energy-consuming system towards one that is more efficient, decentralised, consumer-focused and powered by renewable energy. The international law to limit global warming to below 2°C following the Paris Agreement puts a renewed emphasis on the need for Europe to accelerate the smart energy transition. For the European building stock to effectively contribute to the global climate target, the built environment must undergo a deep transformation and become both smart and efficient.

Some countries have already put in place legislation to take steps towards a smart built environment, such as encouraging the optimisation of the heating system, supporting building energy storage or deploying smart meters. There are also numerous examples showcasing the multiple characteristics of a smart built environment. While these preparatory and inspiring steps are crucial ones, intensification is needed. This means a change of mind-set to recognise buildings as an integral part of Europe's energy infrastructure and make the full use of their wide-ranging abilities.

The current approach of European legislation does not go far enough to encourage smart buildings, only promoting the implementation of smart meters and intelligent metering systems under the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED). This has not been sufficient to overcome barriers to enabling smart buildings. The ongoing review of the EPBD and EED is the prime opportunity to push forward the transition with supportive legislation and embed the principles needed to deliver the benefits of smart buildings to European citizens.

In a recent report, BPIE developed ten principles for buildings to be at the core of a decarbonised energy system making it more flexible, resilient and efficient [1] by saving energy as well as producing, storing and supplying it. Building on these principles, this report assesses the extent to which Member States across Europe are ready for the transition to a highly efficient and smart building stock. This report looks at whether buildings are efficient and healthy, whether they optimise and control the use of resources, and whether they respond to the needs of the energy system and enable renewable energy.

If Europe can ride the wave of the technological revolution, smart buildings will empower the occupants and bring clean energy to all.

MAPPING A SMART-READY BUILT ENVIRONMENT

A smart-ready built environment takes advantage of the full potential of ICT and innovative systems to adapt its operation to the needs of the occupant, to improve its energy performance and to interact with the grid. Smart buildings can play a leading role in transforming the EU energy market, by transforming it into a more decentralised, renewable-based, interconnected and variable system that maximises efficiency and ensures that all resources are used in an optimal way, while at the same time enabling a better living and working environment for the occupants. In order to map out whether Europe is ready for the smart building revolution, some key characteristics of a smart-ready built environment need to be outlined.

The indicators described below do not show how smart the current building stock is, but rather how smart-ready the wider built environment is, based on available data. A smart-ready built environment incentivises the building stock to become smarter. In a smart-ready built environment, citizens and businesses are empowered by the control of their own energy system, producing, storing, managing and consuming energy – whether passively or actively.

First of all, a smart-ready built environment requires **efficient and healthy buildings.** The basic need of most occupants is to have a healthy and affordable home. The building performance, indoor air quality and the ability to keep the indoor temperature at a comfortable level are vital characteristics of a smart built environment. The first of the ten principles for smart buildings is, therefore, maximising the buildings' energy efficiency [1].

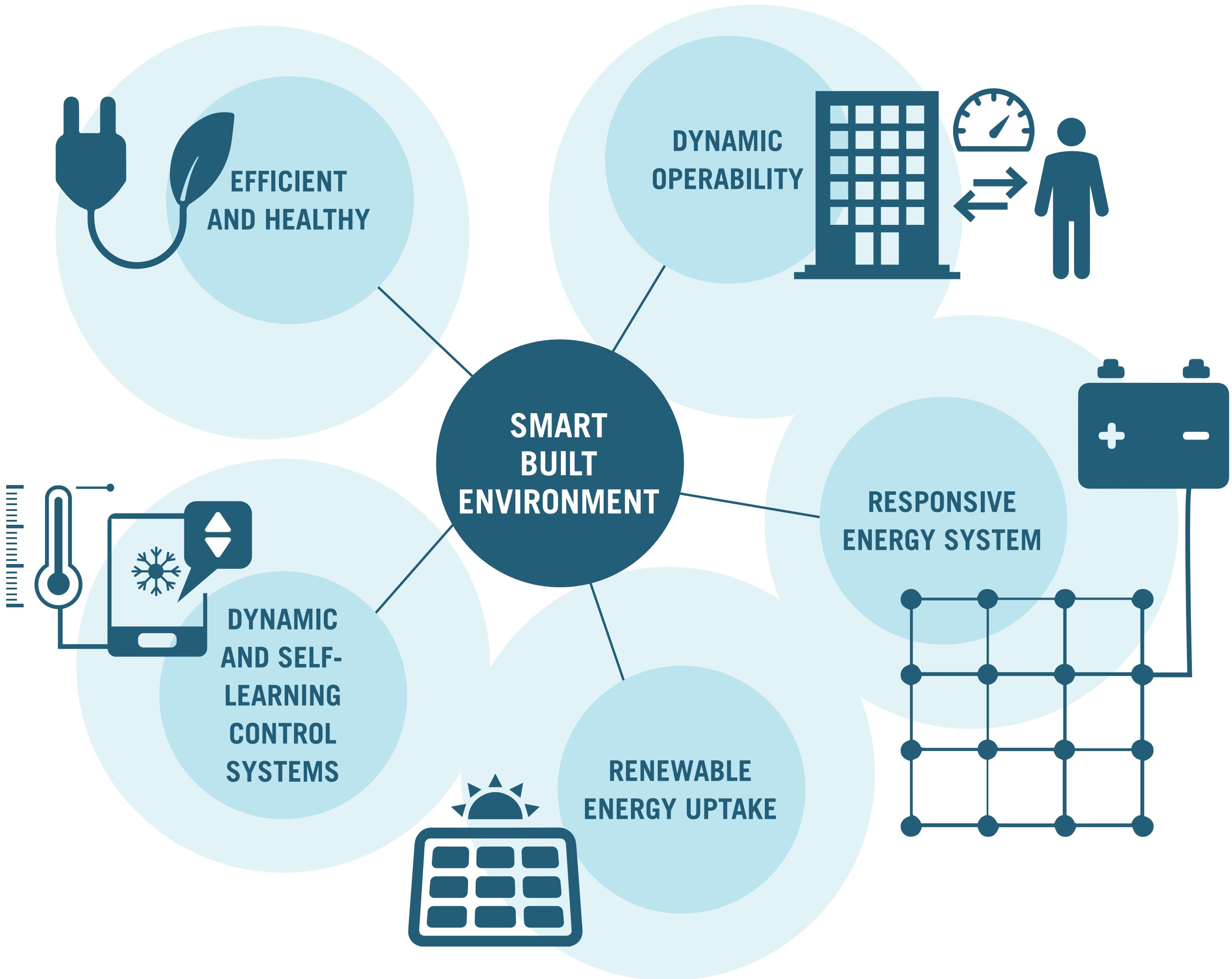
A smart-ready built environment needs **dynamic operability** providing a better indoor environmental quality for the occupants. They should be able to configure the building's technical management system (including options of various levels of automation) based on individual preferences and the system should be able to adapt according to energy needs and price fluctuations. In other words, the building should empower occupants with control over the energy flow, through connected technical building systems and other appliances inside the building (for example, smart thermostats and refrigerators, as well as security and access-related systems).

A smart built environment requires **energy-system-responsive** buildings, ready to answer the needs of the electricity, district heating and cooling grids and the broader energy system, for instance in case of peak loads. Buildings could play a key role in balancing the grid and enabling a wider uptake of electric vehicles. In order to do so, buildings must be entitled to participate in electricity markets with demand response and building energy storage capacity.

A smart-ready built environment enables **renewable energy uptake**. The EU's vision to decarbonise the building stock by 2050 requires a much greater share of renewable energy in the establishment of the building stock's energy requirements. Buildings can facilitate the greater uptake of renewables in many different ways, such as self-production (with photovoltaics, solar thermal and geothermal) or by inter-operating in a smart district where a number of buildings optimise the use of renewable energy (through a district biomass heating system, fuel cells or using waste heat).

Finally, a smart built environment needs proper **dynamic and self-learning control systems**[1], in order to optimise the various interactions and energy uses. This feature enables buildings to become truly smart and ensures synergies between different operations within the building and the energy system. Buildings are smart when optimising the interplay between individualised consumer settings and physical energy flows e.g. in heating, cooling and ventilation systems. For example, automatic hydraulic balancing of fluid distribution in water-based heating and cooling systems or self-learning thermostats can ensure intended indoor climate at an optimal energy efficiency and minimal operating cost.

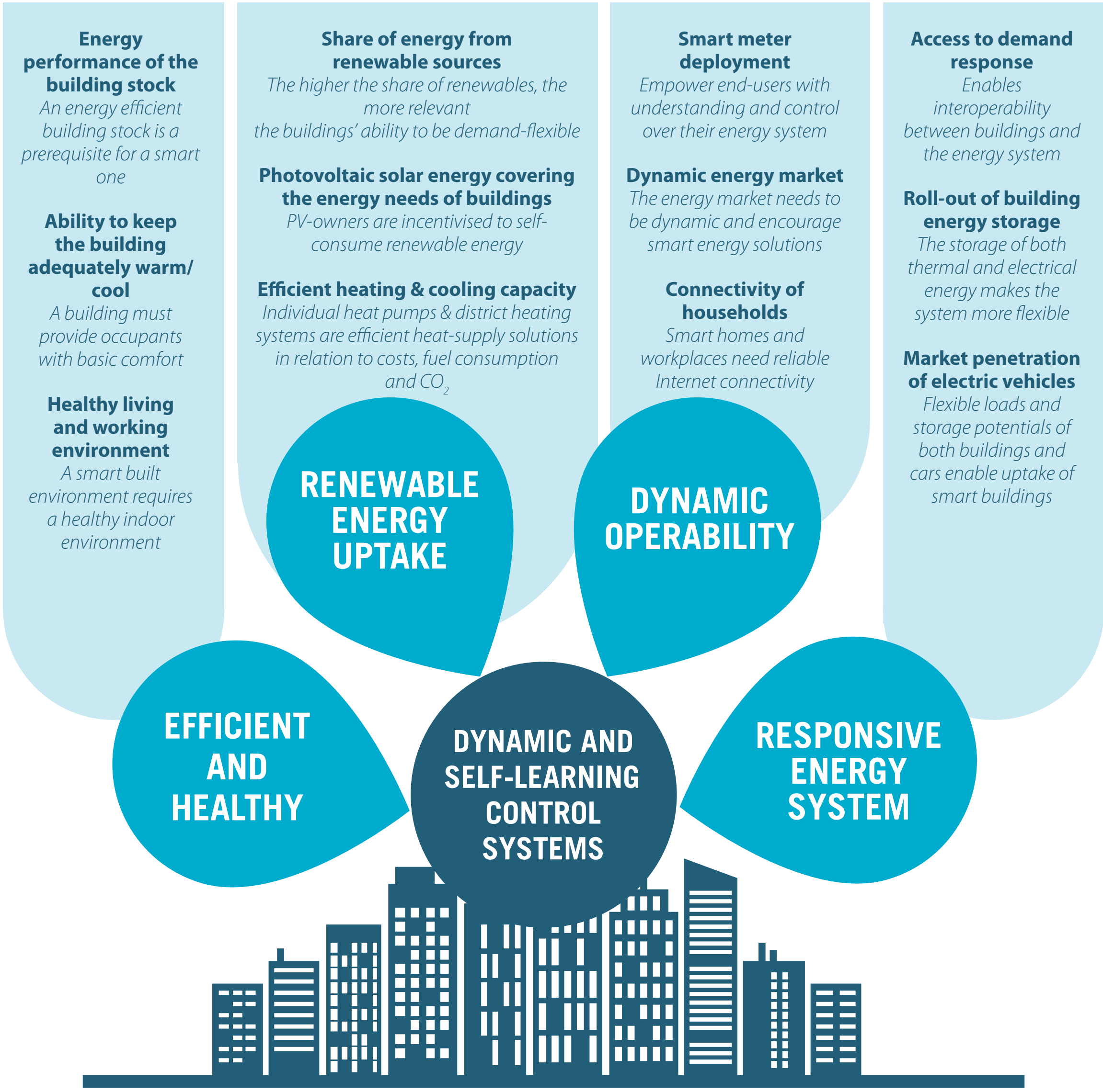
Figure 1 - Five pillars of a smart built environment (Source: BPIE own analysis)



In mapping the smart-ready level of the built environment in the 28 EU Member States, 12 essential characteristics were defined. These characteristics have been selected based on the ten principles of a smart built environment as outlined in the report 'Smart buildings in a decarbonised energy system' [1]. Mirroring the smart built environment, the characteristics are heterogeneous and interdependent.

[1] Dynamic and self-learning control systems can also refer to Building Automated Control Systems (BACS), Building Automation Technologies (BAT) and Home and Building Energy Management Systems (HEMS/BEMS)

Figure 2 – Characteristics of a smart built environment (Source: BPIE own analysis)



The characteristics of a smart built environment are interdependent and not solely relevant for the category they are assigned to. For example, demand response cannot be fully utilised unless smart meters are available and photovoltaics and building energy-storage solutions enable electric vehicles to be charged with renewable energy. In order for the built environment to be considered smart, it should encompass a high score for the vast majority of these essential characteristics.

The 12 characteristics described in Figure 2 are given equal importance in the analysis. Three of them are valued through equally weighted indicators: *Building energy performance* through *Building envelope performance* and *Final energy consumption*; *Dynamic energy market* through *Dynamic pricing* and *Flexible market;* and *Efficient heating and cooling* through *Heat pumps* and *District heating*. Therefore, the 12 characteristics translate into 15 indicators, described in the next section.

The selection of data underpinning the indicators has - to some extent - been affected by data scarcity. As Figure 2 illustrates, dynamic and self-learning control systems are crucial to a smart built environment, enabling many 'smart' features. Currently, reliable data on country-level is not available to accurately assess this aspect.

Figure 3 - Smart-Ready Built Environment Indicators[2] (Source: BPIE own analysis)

$$SBEI = \frac{\left(\left(\frac{BEP + FEC}{2}\right) + CMF + IAQ\right) + \left(SM + \frac{DP + FLX}{2} + CON\right) + \left(DR + BES + EV\right) + \left(RES + PV + \frac{HP + DH}{2}\right)}{12}$$

SBEI= Smart Built Environment Indicator

BEP = Building envelope performance
(Source: EU Building Stock Observatory [2] - Year of data: 2014)

$$= \frac{U\ value^{residential}}{\%\ residential} + \frac{U\ value^{non\text{-}residential}}{\%\ non\text{-}residential}$$

FEC = Final energy consumption
(Source: EU Building Stock Observatory [2] - Year of data: 2014)

$$= \frac{Energy\ consumption^{residential}}{\%\ residential} + \frac{Energy\ consumption^{non\text{-}residential}}{\%\ non\text{-}residential}$$

CMF = Ability to keep adequately warm/cool
(Source: EU Building Stock Observatory [2] - Year of data: 2014)

$$= 1 - \frac{\%\ of\ pop\ incapable\ to\ keep\ home\ (warm+cool)}{2}$$

IAQ = Healthy living and working environment
(Source: EU Building Stock Observatory [2] - Year of data: 2013)
= 1- (% of population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor)

RES = Renewables energy consumption
(Source: Eurostat [5] [7] - Year of data: 2014)
= % of renewables in final energy consumption

PV = Photovoltaics
(Source: Eurostat [5] [7] - Year of data: 2014)

$$= \frac{PV\ Production\ (TOE)}{population * energy\ need\ per\ capita}$$

HP = Heat pumps
(Source: EU Building Stock Observatory [2] - Year of data: 2014)
= % of population with heat pumps

DH = District heating
(Source: European Commission JRC [10] - Year of data: 2005)
= Share of district heating in final energy consumption for heating

SM = Smart meter deployment
(Source: Acer [13] - Year of data: 2015)
= % dwellings with a smart meter

DP = Dynamic pricing
(Source: Acer [13] - Year of data: 2015)
=% of standard household consumers supplied under dynamic pricing for supply and network charges of electricity in EU MS

RES = Renewables energy consumption
(Source: Eurostat [5] [7] - Year of data: 2014)
= % of renewables in final energy consumption

FLX = Flexible market
(Source: EU Building Stock Observatory [2], ACER [14] - Year of data: 2014)
= Market share of the largest generator in the electricity market + switching rates (electricity)

CON = Connectivity
(Source: Eurostat [3] - Year of data: 2016)
= % households with Internet connection

DR = Demand response
(Source: SEDC [8], EC JRC [9] - Year of data: 2015)
= Evaluation (based on assessments made by JRC and SEDC) of the demand response market

BES = Building energy storage
(Sources: GTAI [15], European Commission's DG Energy [11] - Year of data: 2016)
=% of buildings with energy storage

EV = Electric vehicles
(Sources: ACEA [15] - Year of data: 2015)
= The market share of EVs of total new car registrations

2 Future versions of the Smart Built Environment Indicator should aim to incorporate data on dynamic and self-learning control systems, in order to provide a more complete picture.

DESCRIPTION OF THE INDICATORS

This section describes all the indicators in detail. For every indicator, the countries are given a score between 1 (not smart-ready) to 5 (smart-ready). For example, the smart-ready level of *performance of the building stock* is a highly-energy-efficient building stock, in line with the requirements for nZEBs (nearly Zero-Energy Buildings). A score of 1 is then given to countries with a highly inefficient building stock, with an average U-value higher than 1.80, which represents a non-insulated wall built in the post-war period.

Indicator data has primarily been gathered from the EU Building Stock Observatory[3] [2] and Eurostat [3] [4] [5] [6] [7]. Other sources include the Smart Energy Demand Coalition (SEDC) [8], the European Commission's Joint Research Centre (JRC) [9] [10], the European Commission's DG Energy [11], the Agency for the Cooperation of Energy Regulators (ACER) [12] [13], GTAI [14] and the European Automobile Manufacturers Association (ACEA) [15] .

BUILDING ENVELOPE

An energy efficient building enables the end-user to shift its heating or cooling demand: well-designed and efficient buildings maintain the desired indoor temperature better and over a longer period, which makes them more appropriate for pre-heating or pre-cooling, allowing energy consumption shifts to other time periods. The smart-ready level is similar to nZEB regulations (W/mK = 0.29) [16], while the lowest score is given to countries with an average U-value (W/mK) higher than 1.80, which is similar to a non-insulated wall built in the post-war period in Europe [17].

BUILDING ENVELOPE	
Grade	*U-value*
5	<0.29
4	0.29 - 0.80
3	0.81 - 1.30
2	1.30 - 180
1	>1.80

The grading for this indicator is based on data from the EU Building Stock Observatory [2].

FINAL ENERGY CONSUMPTION

Energy efficient buildings, smart controls and the behaviour of the occupant can all have significant effects on the final energy consumption. The smart-ready level is equal to existing nZEB examples (kWh/m² = 50) [18], while a lower score is given to countries with an average kWh/m² higher than 248, which is similar to the final energy consumption of a building dating from the post-war period in Europe [19].

FINAL ENERGY CONSUMPTION	
Grade	*kWh/m²*
5	<50
4	50 - 115
3	116 - 182
2	183 - 248
1	>248

The grading for this indicator is based on data from the EU Building Stock Observatory [2].

ABILITY TO KEEP ADEQUATELY WARM/COOL

Energy poverty is a major problem for Europe, as between 50 and 125 million people are unable to afford a proper indoor thermal comfort [20]. Providing occupants with thermal comfort is a central service of buildings. The smart-ready level is equal to a society where nearly all occupants can afford to keep their home and workplace adequately warm/cool. The lowest score is given to countries with more people at risk of poverty or social exclusion than the EU average in 2014 (i.e. more than 25%) [21].

ABILITY TO KEEP ADEQUATELY WARM/COOL	
Grade	*Share (%)*
5	>99
4	92 – 99
3	84 – 91
2	75 – 83
1	<75

The grading for this indicator is based on data[4] from the EU Building Stock Observatory [2].

[3] The EU Building Stock Observatory is a newly-launched initiative by the European Commission (end of 2016) - an online data portal for the European building stock and related key policies.

[4] Data only available for the residential sector.

HEALTHY LIVING AND WORKING ENVIRONMENT

The presence of a leaking roof, damp walls, floors or foundation, or rot in window frames or floors causes serious health problems for Europeans [20]. The smart-ready level is equal to a society where nearly all occupants have a healthy living and working environment. The lowest score is given to countries with more people at risk of poverty or social exclusion than the EU average in 2014 (i.e. more than 25%) [21].

HEALTHY LIVING AND WORKING ENVIRONMENT	
Grade	Share (%)
5	>99
4	92 – 99
3	84 – 91
2	75 – 83
1	<75

The grading for this indicator is based on data[5] from the EU Building Stock Observatory [2].

SMART METER DEPLOYMENT

Smart meters can empower end-users by enabling them to have better understanding and control over their energy system. Accurate measurement of the energy consumption to provide real-time data on the energy used is a requirement to valorise demand response services. The smart-ready level is set to be equal to a full deployment of smart meters. The lowest score is given to countries where the smart meter deployment had not started by 2015 (the year with the most recent data).

SMART METER DEPLOYMENT	
Grade	Share (%)
5	>99
4	50 - 99
3	25 - 49
2	1 - 24
1	<1

The grading for this indicator is based on data from the Agency for the Cooperation of Energy Regulators (ACER) [12].

CONNECTIVITY

Levels of connectivity are measured by the number of households with a broadband connection. Accessibility to fast and reliable Internet is a fundamental need for a smart building. The smart-ready level is equal to a highly-connected society, where practically all buildings are connected to the Internet. The lowest score is given to countries where one out of four households does not have access to Internet.

CONNECTIVITY	
Grade	Score (%)
5	>99
4	92 – 99
3	84 – 91
2	75 – 83
1	<75

The grading for this indicator is based on data from Eurostat [3].

DYNAMIC PRICING

Thanks to technological advances, dynamic pricing is now a possible path to energy savings, leading to a smarter use of energy from the grid and easing of peak loads. The availability of dynamic price signals for commercial and residential consumers is a requirement for demand response. The smart-ready level is equal to a framework with fully dynamic pricing. The lowest score is given to countries where the electricity market has none of the dynamic pricing characteristics.

The grading for this indicator is based on data from the Agency for the Cooperation of Energy Regulators (ACER) [12].

DYNAMIC PRICING	
Grade	Evaluation of electricity market
5	Fully dynamic pricing
4	Hourly pricing (for majority of users)
3	Hourly pricing (for minority of users)
2	Static Time of Use pricing
1	Fixed pricing

5 Data only available for the residential sector.

FLEXIBLE MARKET

A flexible electricity market fosters manoeuvrability for consumers and competition among utility companies. To assess both consumer flexibility and competition on the market, the indicator looks at how many consumers are switching electricity providers per year (switching rates) as well as at the market share of all utility companies except the largest one. For example, if the switching rate in a country is 10% per year (i.e. 10% are changing electricity provider during the year) and the biggest utility company has 60% of the market, the score will be 50 =10+(100-60). The smart-ready level is equal to a framework that is very flexible and competitive. The lowest score is given to countries with very little competition on the electricity market and with barriers for consumers to switch provider.

FLEXIBLE MARKET	
Grade	*Score*
5	>90
4	75 - 90
3	60 - 74
2	45 - 59
1	<45

The grading for this indicator is based on data from Eurostat [4] and ACER [13].

DEMAND RESPONSE

Demand response is the ability to shift energy demand by reducing peak consumption and avoiding grid imbalance. It is an important enabler for security of supply, renewable integration, increased market competition and end-user empowerment. The grading reflects the Smart Energy Demand Coalition's (SEDC) assessment [7] of "consumer access to demand response" in 14 EU Member States combined with the Joint Research Centre's (JRC) [8] qualitative status evaluation of demand response in all 28 Member States. The smart-ready level is equal to a framework that is commercially open for demand response. The lowest score is given to countries with a closed market for demand response.

DEMAND RESPONSE	
Grade	Evaluation of DR market
5	Commercially open
4	Open for majority of actors
3	Open only for major industries/actors
2	Very low participation
1	Closed

The grading for this indicator is based on data from SEDC [8] and the JRC [9].

BUILDING ENERGY STORAGE

In an increasingly complex energy environment, technologies that can rapidly adapt to operating loads, absorb or release energy when needed, or convert a specific final energy into another form of energy will be highly valued. Battery-based projects are likely to be an important part of future building-related storage, but other technology options, such as thermal and hydrogen storage, must also be considered. The smart-ready level is equal to a built environment where 3% of the building stock has been equipped with building energy storage in the past year. The lowest score is given to countries with next to no market penetration of building energy storage.

BUILDING ENERGY STORAGE	
Grade	*Share of dwellings*
5	>1
4	1 - 3
3	0,1 - 0.99
2	0,001 - 0.099
1	<0,001

The grading for this indicator[6] is based on data from GTAI [14] and the European Commission's DG Energy [11].

[6] Due to the lack of data, our estimation is based on electrical storage in the residential sector.

ELECTRIC VEHICLES

Intelligent solutions will manage supply and demand between cars and buildings, and use their separate storage facilities in an optimal way. Combining flexible loads and decentralised storage potentials of both buildings and cars will maximise the local integration of renewable energy. The smart-ready level is equal to a scenario where all new vehicles are electric. The lowest score is given to the countries with almost no market penetration of electric vehicles.

The grading for this indicator is based on data from ACEA [15].

ELECTRIC VEHICLES	
Grade	*Share of EVs from new car registrations*
5	>75
4	50 – 75
3	25 – 49
2	10 - 24
1	<10

RENEWABLE ENERGY

The higher the share of renewable energy in the system, the more demand flexibility and smart control incentivised by the market and encouraged by public authorities. Additionally, the more energy efficient the stock (the lower energy demand), the higher the share of renewables will be. The smart-ready level is equal to an analysis of power system flexibility [22], where their mid-term regime (of 50% variable renewable energy) requires storage, demand flexibility and a dynamic energy market (i.e. smart buildings). The lowest score is given to countries with less than 10% of gross final energy consumption from renewable energy.

The grading for this indicator is based on data from Eurostat [6].

RENEWABLE ENERGY	
Grade	*Share of gross energy consumption*
5	>50
4	38 – 50
3	24 – 37
2	10 – 23
1	<10

PHOTOVOLTAIC SOLAR ENERGY

The trend for businesses, households and local communities to produce their own energy opens new cost-containment opportunities. Under grid parity, consumers can save money by generating their own energy, rather than buying it from the grid. The smart-ready level is equal to the High-Ren scenario for Europe outlined in the IEA's technology roadmap, describing the required share of PV in the energy system to reach a 50% reduction in energy-related CO_2 emissions by 2050. The lowest score is given to countries with almost no market penetration of PV.

The grading for this indicator is based on data from Eurostat [6].

PHOTOVOLTAICS	
Grade	*Share of gross energy consumption*
5	>8
4	6 - 8
3	3 – 5
2	1 – 2
1	<1

HEAT PUMPS

When using electricity and thermal energy from renewable sources, heat pump systems provide a 100%-renewable solution for heating and cooling of buildings. The use of heat pumps can also be steered towards flexible use and demand response according to grid needs. The smart-ready level is equal to the IEA's BLUE map scenario for 2050, where the capacity of heat pumps needs to grow 6.6 more times compared to today's level [23] (calculated for EU). The lowest score is given to countries with an insignificant share of energy production from heat pumps.

HEAT PUMPS	
Grade	*Share of primary energy consumption*
5	>6.50
4	4.01 - 6.50
3	1.51 - 4.00
2	0.10 - 1.50
1	<0.10

The grading for this indicator is based on data from the EU Building Stock Observatory [2].

DISTRICT HEATING

In a dynamic energy market, end-users connected to district heating could even sell their excess energy, cutting down the heat-load peak and allowing the district heating supplier to avoid running peak-load boilers, often fuelled by conventional energy sources. District heating could integrate excess heat (e.g. heat recovery of cooling systems or data centres), heat pumps driven by photovoltaic solar panels, as well as geothermal and solar thermal energy.

DISTRICT HEATING	
Grade	*Share of DH in final energy consumption for heating*
5	>50
4	34 - 50
3	18 - 33
2	1 - 17
1	<1

The smart-ready level is equal to the Heat Roadmap Europe's ambitious scenario for Europe's energy future [24]. The lowest score is given to countries with an insignificant share of district heating.

The grading for this indicator is based on data from the EU JRC [10].

STATUS: SMART-READINESS OF THE BUILT ENVIRONMENT

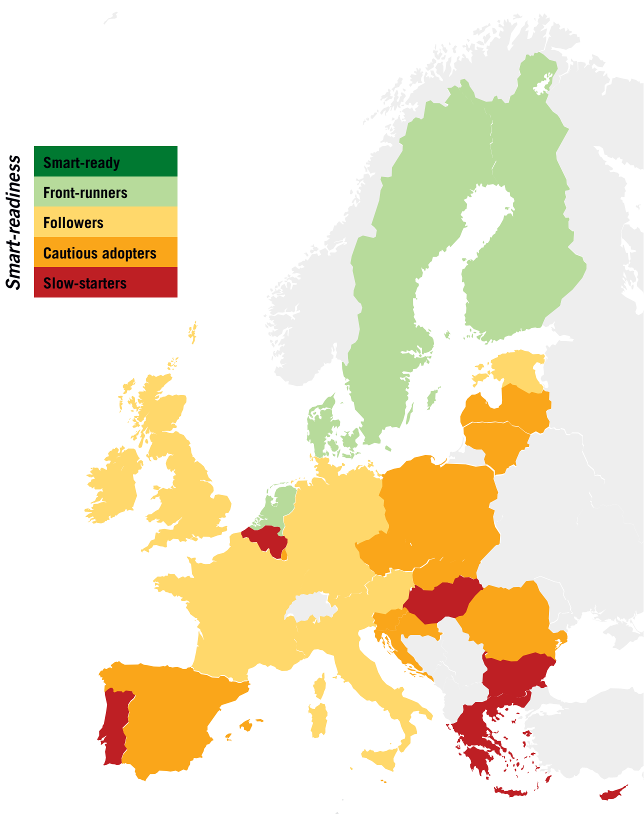
Europe's building stock is entering a transition phase, becoming an active player in the energy system - controlling, producing, storing and consuming energy. The explosion of smart technologies – the Internet of Things – enabling a more efficient use of energy in buildings will inevitably redesign the built environment and the linked energy flows. The existing building stock was not constructed for this purpose - what is now technologically possible was only speculation just 10 years ago.

The first section outlines the overall score based on the indicators and calculations described in Figure 4. The following section then zooms in on four key indicators.

IS EUROPE READY FOR SMART BUILDINGS?

Figure 4 answers the question *Are the European countries ready for smart buildings*? with a clear NO. No country is fully ready to take advantage of the benefits the smart revolution will entail, including greener, healthier and more flexible energy use.

Figure 4 - Smart-readiness across Europe (Sources and calculation: see Figure 3)

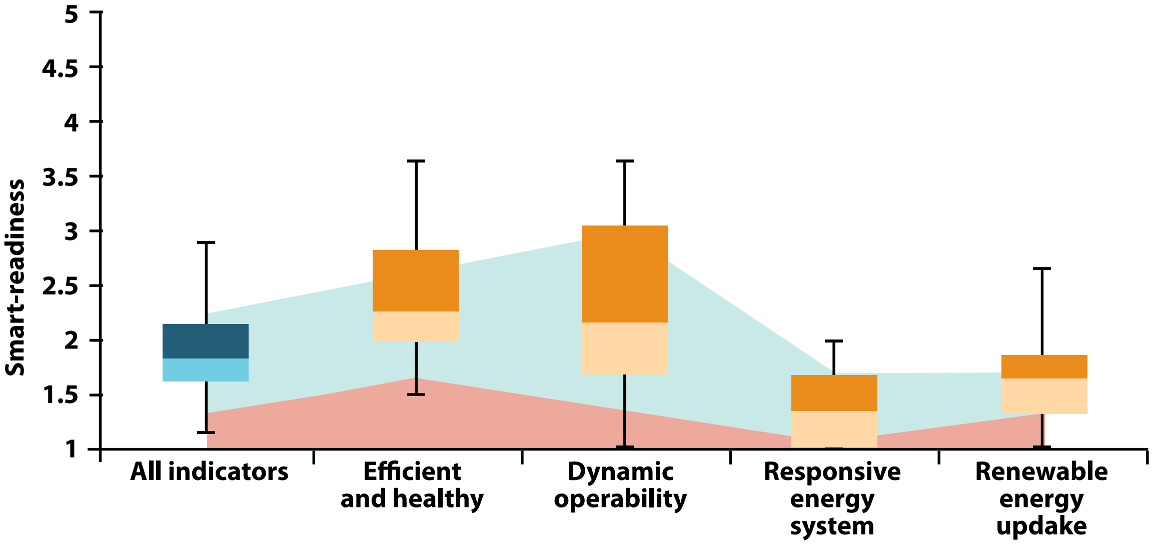


The aggregated smart built environment indicator result ranges from 1.13 (Cyprus) to 2.92 (Sweden) out of 5. The box plot below shows the average score for all countries divided upon the four categories (described in Figure 2). The light blue and red colours in the background illustrate the average score among the top five and bottom five countries, respectively.

The figure shows that the big difference among countries can be found under the categories efficient and healthy and dynamic operability. It can be explained by the fact that the top countries have more insulated and healthier buildings, better smart infrastructure (smart meters and connectivity) and better-prepared regulatory frameworks (demand response and dynamic pricing). The average score for the categories responsive energy system and renewable energy uptake ranges from low to very low.

The overall modest score illustrates that the EU has a major infrastructure challenge to ensure the building stock becomes future-proof and contributes to climate change mitigation and adaptation.

Figure 5 - Box plot showing distribution of average score for all countries (Source: BPIE own analysis)



Sweden, Finland, Denmark and the Netherlands are the leading countries, which is due to progressive policies such as smart meter roll-out and investments in renewable energy. The countries also have a long history of effective building regulations. But even in these countries there is room for improvement, due to rather closed markets for demand response and no market penetration of building energy storage capacity.

Most of the *slow-starters* score low on all the indicators except *final energy consumptio*n, which can be explained by climate conditions and financial restrains, rather than by highly-developed energy efficiency measures. This is confirmed by the low score for the same countries on the indicator *ability to keep adequately warm/cool*.

The table below shows the underlying indicators and their respective scores per country. The overall low score can be partly explained by rigid regulatory frameworks (see demand response and flexibility in the market), lack of investments (see building energy performance and smart meters), but also by the recent market penetration of some of the indicators, such as *building energy storage, electric vehicles and demand response*.

Building energy storage and electric vehicles are the two indicators with the lowest aggregate score. However, interest in these solutions is growing rapidly, marked by decreasing prices and an increase in service offers. In the case of electric vehicles, the Netherlands is in the lead with almost 10% of newly registered vehicles being electric, while Germany - through a building-energy-storage programme - succeeded to heavily increase the market share of smart and environmentally-friendly alternatives.

Table 1 – Smart built environment results (Source: BPIE own analysis)

		Sweden	Finland	Denmark	Netherlands	Estonia	United Kingdom	Austria	Germany	France	Ireland	Italy	Spain	Poland	Latvia	Slovakia	Slovenia	Czech Republic	Luxembourg	Malta	Romania	Croatia	Lithuania	Belgium	Greece	Portugal	Bulgaria	Hungary	Cyprus
BUILDING PERFOR-MANCE	Building Envelope (U-value)	◕	◕	◑	◔	◕	○	◑	◑	◔	◔	○	○	◔	◑	◔	◑	◑	◔	○	◔	○	◑	○	○	◔	◔	◔	○
	Final Energy Consumption	◔	○	◑	◑	○	◔	◔	◔	◔	◑	◔	◑	◔	○	◔	○	◔	○	◕	○	◔	◑	○	◑	◕	◑	◑	◕
HEALTHY LIVING & WORKING ENVIRONMENT		◕	◕	◑	◑	◑	◔	◑	◑	◑	◑	◔	◔	◑	○	◕	○	◑	◑	◑	◑	◑	◔	◔	◑	○	◑	○	○
ABILITY TO KEEP AD-EQUATELY WARM/COOL		◕	◑	◕	◑	◑	◕	◑	◑	◑	◕	◔	◔	◔	◔	◑	◑	◑	◕	○	◔	◔	○	◑	○	○	○	◔	○
SMART METER DEPLOYMENT		●	●	◕	◑	◕	◔	◔	○	◔	○	●	◕	◔	◔	○	◑	○	○	◕	◔	○	○	○	○	○	○	○	○
DYNAMIC MARKET	Flexibility in the market	◑	◕	◑	◑	○	●	◔	◕	○	◑	◕	◕	◕	◔	○	◔	◔	○	○	◑	○	◕	◔	○	◕	○	◔	○
	Dynamic pricing	◑	◔	◔	◔	◑	◑	○	◔	◑	◔	◔	◑	◔	◑	◔	◔	◔	○	○	◑	◔	◑	◔	◔	◑	○	◔	○
CONNECTIVITY		◑	◑	◕	◕	◑	◕	◑	◑	◔	◑	◔	◔	◔	◔	◔	◔	◔	◕	◔	○	◔	○	◔	○	○	○	◔	○
DEMAND RESPONSE		◑	◕	◔	◑	○	◕	◑	○	◕	◑	○	○	◔	◔	◔	◔	○	○	○	○	○	○	◑	◔	○	○	◔	○
BUILDING ENERGY STORAGE		○	○	○	○	○	○	○	◔	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
ELECTRIC VEHICLES		○	○	◔	◔	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
EFFICIENT HEATING CAPACITY	District heating	◑	◑	◑	◔	◑	○	◔	◔	○	○	○	○	◑	◑	◔	◔	◔	◔	○	◔	◔	◑	○	○	○	○	◔	○
	Heat pumps	◑	◔	◔	◔	◔	○	◔	◔	◔	◔	◑	○	○	○	○	◔	◔	○	◔	○	○	○	○	◔	○	◔	○	○
RENEWABLE ENERGY		●	◕	◑	○	◑	○	◑	◔	◔	○	◔	◔	◔	◕	◔	◔	◔	○	○	◑	◑	◔	○	◔	◑	◔	○	○
PHOTOVOLTAICS		○	○	○	○	○	○	○	◔	○	○	◔	◔	○	○	○	○	○	○	◔	○	○	○	○	◔	○	◔	○	○
SMART-READINESS		Sweden	Finland	Denmark	Netherlands	Estonia	United Kingdom	Austria	Germany	France	Ireland	Italy	Spain	Poland	Latvia	Slovakia	Slovenia	Czech Republic	Luxembourg	Malta	Romania	Croatia	Lithuania	Belgium	Greece	Portugal	Bulgaria	Hungary	Cyprus

FOUR KEY INDICATORS UNDER THE SPOTLIGHT

This section zooms in on four of the underlying indicators to provide a better understanding of what lies beneath. The four selected indicators presented in this section are not necessarily more important than any of the remaining eight, but are somewhat central to the category they represent..

PERFORMANCE OF THE EXISTING BUILDING STOCK

Energy efficient buildings facilitate a smarter energy use and an affordable living situation for the occupant. It also allows for the optimal use of other aspects, such as demand flexibility and heat pumps.

DEPLOYMENT OF SMART METERS

Smart meters provide information about the real-time energy use and empower the occupants with control of their energy consumption. It should enable a two-way communication between the building use and the wider energy system.

DEMAND RESPONSE AVAILABILITY

Demand response is a central feature of the interaction between smart buildings and the wider energy system. Buildings can use energy in a more flexible way, enabling the grid to adapt demand when beneficial.

SHARE OF ENERGY FROM RENEWABLE SOURCES

Climate-friendly energy will have to be the main source of energy in a smart-ready built environment. A bigger share of renewables in the society also requires smarter buildings to have the ability to balance the more volatile flow of energy.

BUILDING PERFORMANCE

A highly-energy-efficient building stock, made possible by deep renovation and efficient new buildings, brings multiple benefits to demand reduction as well as enables demand response, increasing the share of variable renewable energy in the total energy consumption.

An energy-efficient building also allows the end-user to shift its heating or cooling demand: well-designed and efficient buildings maintain the desired indoor temperature better and over a longer period, which makes them more appropriate for pre-heating or pre-cooling, allowing energy consumption shifts to other time periods.

The figures below illustrate how poor the energy performance of the European building stock is, both in terms of designed and actual energy use. The colder Nordic and Baltic countries have a more insulated building stock, but also a higher energy demand, which to a certain extent is due to the colder climate in this region. Following this pattern, the least energy-efficient buildings and a lower energy use can be found in some of the countries with the warmest climate – Spain and Greece. Although, there are exceptions to the geographical divide: Denmark, the Netherlands and Lithuania score relatively well in both figures, while Italy and Belgium are at the lower end.

It is important to reflect on and cover both actual and designed heat use. After finalising 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 windows for ventilation, turning on the air-conditioning if too warm, switching on the lights, etc. Very often, this behaviour leads to the calculated final energy demand and the real-measured final energy demand being very different. Monitoring systems and dynamic, or even self-learning, control systems could help mitigate this mismatch and ensure a high actual energy performance of the building.

Figure 6 - Building envelope (U-value of building envelope for residential and non-residential buildings) (Source: EU Building Stock Observatory [2])

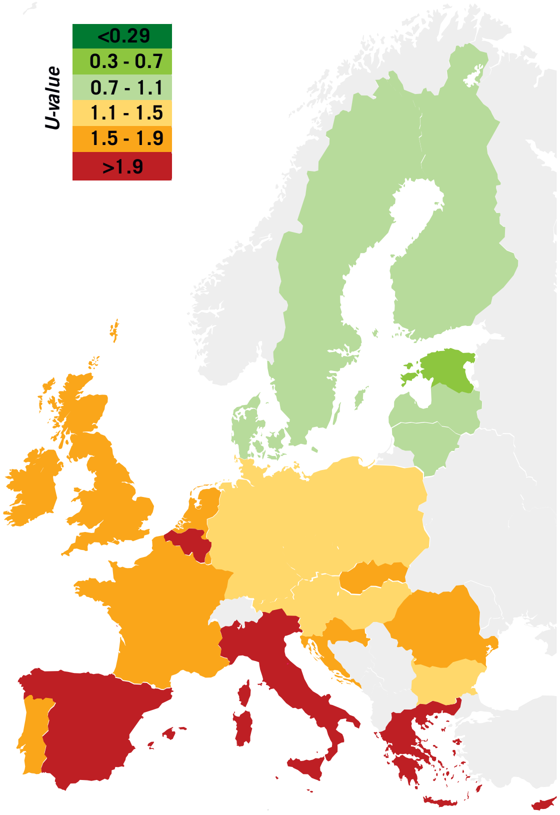
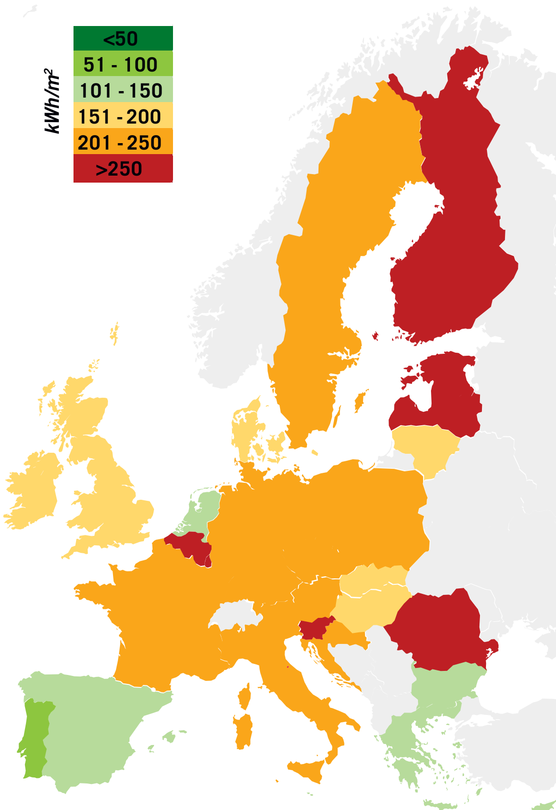


Figure 7 - Final energy consumption under normal climate conditions (kWh/m² for residential and non-residential buildings) (Source: EU Building Stock Observatory [2])

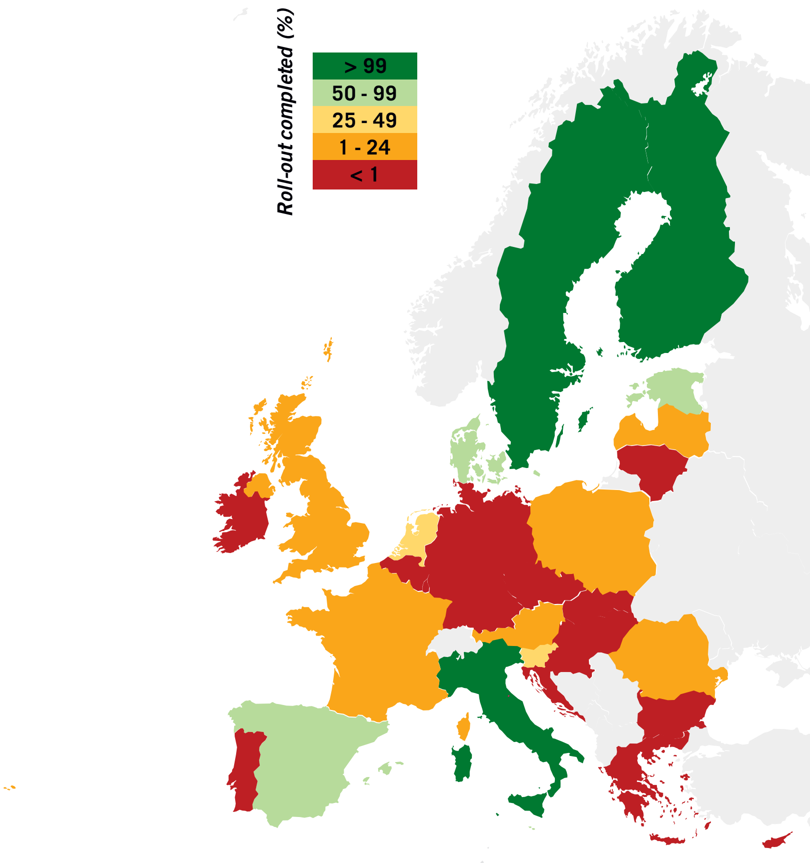


SMART METERS

The EU "aims to replace at least 80% of electricity meters with smart meters by 2020, wherever it is cost-effective to do so" [25]. According to the Joint Research Centre: "by 2020, it is expected that almost 72% of European consumers will have a smart meter for electricity, while 40% will have one for gas" [26]. A smart meter is an electronic device that records energy consumption and should enable a two-way[7] communication between the consumer and the utility company. Accurate measurement of the energy consumption to provide real-time data on the energy used is a requirement to valorise demand response services. Without smart meters allowing end-users – in particular residential and commercial users – to be compensated for the savings achieved through demand response actions, will lead the market to lose its main incentive, and it may block the full utilisation of demand response.

Figure 8 shows the current state of the smart meter roll-out across EU Member States. Sweden, Finland and Italy have completed their roll-out of smart meters – over 95% of homes are equipped with smart meters. While a few additional countries – Malta, Spain, Estonia, Denmark, Latvia, Poland, Austria and the Netherlands - have made some progress, many countries have not made significant progress.

Figure 8 - Share of household customers equipped with smart meters for electricity in 2016 (Source: The EU Building Stock Observatory [2] and ACER [12])



[7] Not all smart meters on the market enable a smart two-way communication. The early adopters – Sweden and Italy – are currently preparing an upgrade of their smart meters.

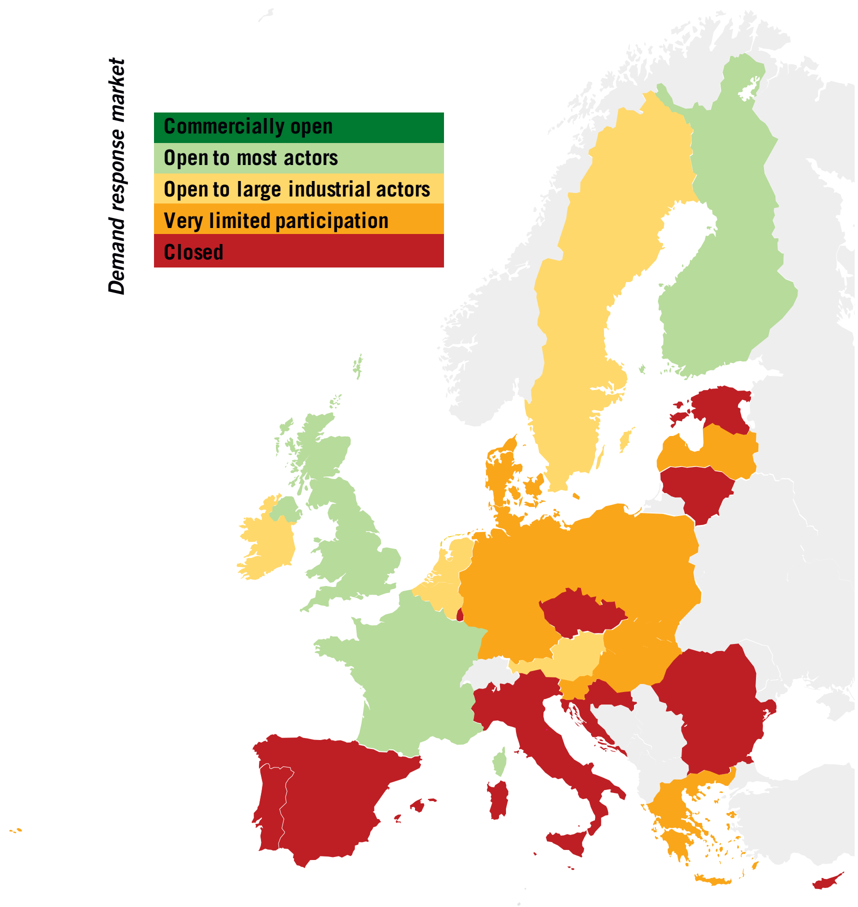
DEMAND RESPONSE

Demand response is an important enabler of security of supply, renewables integration, increased market competition and end-user empowerment. Industrial, commercial and residential end-users could engage in demand response by undertaking different actions: reducing energy use temporarily without a change in consumption during other periods (e.g. lower the indoor temperatures), shifting energy demand to other time periods (e.g. starting to cool a building before peak periods) or temporarily using onsite generation instead of energy from the grid (e.g. generation from renewable energy sources).

Figure 9 shows the level of demand response availability across the EU. The scores reflect the Smart Energy Demand Coalition's (SEDC) assessment [8] of "consumer[8] access to demand response" in 14[9] EU Member States and the Joint Research Centre's (JRC) [9] qualitative status evaluation of demand response in all 28 Member States. SEDC's reviews the regulatory frameworks of all countries and evaluates how open the market is to demand response (from commercially active to closed), while the JRC analyses the status of national regulation concerning the application of Article 15.8 of the Energy Efficiency Directive. Among other things, their study evaluates the authorisation of demand response on the market (allowing consumer load) and the status of legalising and enabling aggregation of demand.

Figure 9 shows that most countries are closed or have a very limited participation of demand response. The leading countries are currently Finland, France and the United Kingdom.

Figure 9 - Implicit demand response availability across the EU in 2015. The score is combining SEDC's and JRC's respective assessments (Source: EC JRC [9] and SEDC [8])



[8] Including residential, commercial and industrial consumers

[9] Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Poland, Slovenia, Spain, Sweden and the United Kingdom

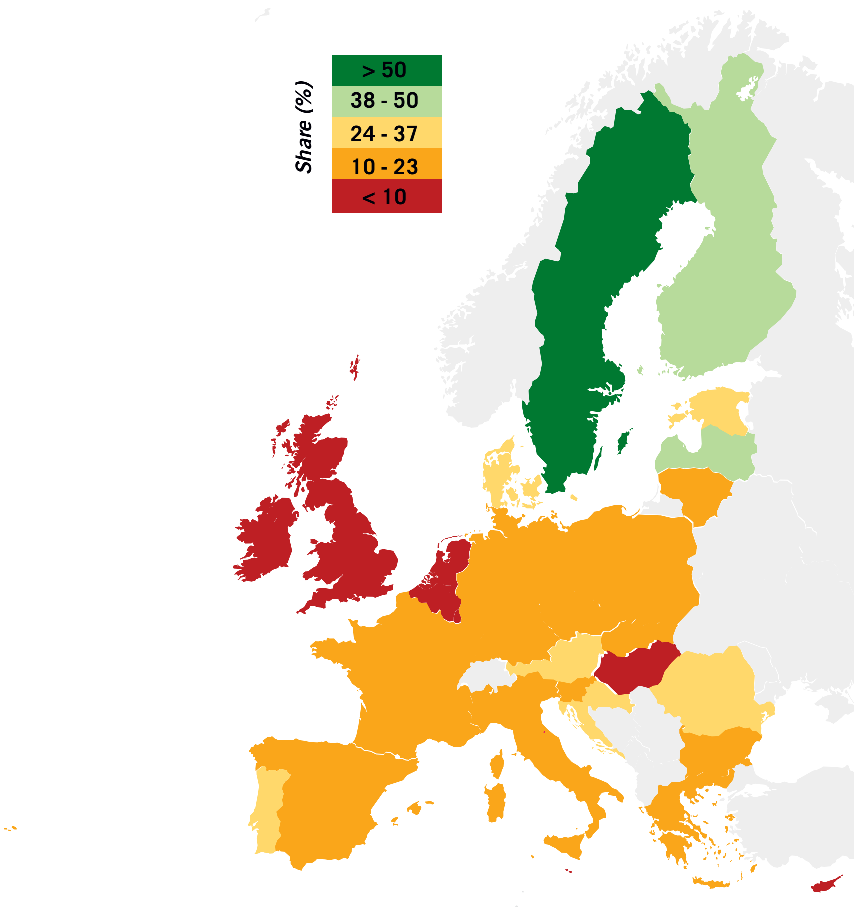
RENEWABLE ENERGY SOURCES

For the EU to meet its energy and climate goals, renewable energy must make a significant contribution to heating, cooling, electricity and mobility. In order to achieve this, the uptake of renewables over the next few decades will need to be far more rapid than it has been to date. Integrating renewables in conventional energy supply systems (such as district heating systems) is one way to facilitate this ambition, in addition to integrated applications in and on buildings.

This is not an evaluation of how well these countries are achieving their renewable energy targets. Rather, it is an assessment of the amount of renewable energy in the energy system since more also means the market and public authorities will incentivise increased demand flexibility and smart control. Additionally, the more energy efficient the stock (the lower energy demand), the higher the share of renewables.

Figure 10 shows the share of renewable energy in gross final energy consumption. Renewable sources include solar thermal and photovoltaic energy, hydro (including tide, wave and ocean energy), wind, geothermal energy and all forms of biomass (including biological waste and liquid biofuels) [5]. The European average in 2014 was 16%, on the path to the EU renewable target of 20% by 2020 and 27% by 2030, although a decarbonised building stock will require a much higher share of renewables. The map illustrates that Sweden, with a big portion of hydro and wind power, has the highest share of energy from renewable sources (over 50%).

Figure 10 - Share of renewable energy in gross final energy consumption in 2014 (Source: Eurostat [5] [7])



SMART LEGISLATION FOR A SMART BUILDING STOCK

Progressive legislative measures covering different sectors in different countries are paving the way for a smarter building stock. For example, Germany has launched a scheme to increase the number of batteries in buildings, while Sweden, Finland and Italy have already completed their roll-out of smart meters. The United Kingdom and France encourage demand response activities, and Denmark is leading on green district heating activities. Electric vehicles are not solely for the early-adopters in the Netherlands. Finland has also invested significantly in generating renewable energy from heat pumps.

As the Heat Roadmap Europe project illustrates [27], the required mix of energy efficiency solutions is different between countries. All 28 Member States should not aim for identical smart built environments, rather tailor the solutions after their country-specific context, culture, energy mix etc.

KFW PUSH FOR PV HOME-STORAGE SOLUTIONS IN GERMANY

Building energy storage for residential and small-enterprises is not yet cost-effective enough to penetrate the market without any policy support. The potential capacity of electric and thermal storage in buildings is huge. Building energy storage in different forms will inevitably play a key role in a decarbonised energy system by increasing self-consumption of renewable electricity and allowing flexible energy consumption, and thereby enabling demand response, benefiting both the occupants and the grid.

The German government is, through its KfW scheme, supporting the increased use of storage in conjunction with photovoltaic systems linked to the electricity grid. The programme offers a 30%-investment-grant on equipment purchased with low-interest loans provided by the German State-owned development bank KfW [28] .

The aim of this scheme is to increase demand for home energy storage and bring down the prices through increased scale and technological advances. The scheme has helped boost the residential energy storage market from almost zero installations two years ago to around 1,000 per month. By the end of 2015, around 35,000 households and commercial operations in Germany had invested in a PV-battery system [29]. While the scheme might not seem perfect, policies like this are needed to boost the market uptake of building energy storage.

SWEDEN HAS ALREADY FINISHED THE DEPLOYMENT OF SMART METERS

Large-scale deployment of reliable smart meters is considered as one of the first steps towards a smart, integrated and efficient energy system. Sweden was an early adopter and achieved a full roll-out of smart meters already in 2009. Since the 1st of July 2009, billing of electricity use in Swedish homes must take place monthly and should be based on real consumption data. 95% of the smart meters in Sweden can collect hourly readings while about 80% are prepared for a two-way communication. Smart meters facilitate a direct link between the homeowner or occupant and the energy provider, which increases transparency and enables a smarter energy planning.

Figure 11 - Smart meter (Source: Diginomica)

This transition has been induced by a legal decision to make monthly-meter-reading available to customers, which in turn led to a decision by distribution companies to roll-out smart meters to meet this requirement [30].

FRANCE IS OPENING UP FOR DEMAND RESPONSE

Demand response is considered as a key enabler for security of energy supply, renewables' integration, improved market competition and consumer empowerment. Demand response in buildings can generate a more efficient energy system and allow energy consumers to save money on their energy bills. Demand response is generally available for industry, but not yet for commercial and residential sectors. France has, however, been one of the most progressive countries in opening up the market for demand response.

France is the first country to have put in place workable market rules for demand response. For example, regulators have made it possible for third-party aggregators to have contracts with consumers to provide demand response without the supplier's agreement. Imbalances are neutralised by the transmission system operator (TSO), whereas a sourcing price for electricity is defined centrally thus enabling the balance-responsible-party to avoid being penalised by demand response activation [8]. This allows for new business models to aggregate demand and other innovative solutions.

DISTRICT HEATING IN DENMARK BRINGS ENERGY SECURITY, RENEWABLES AND SMART CITIES

Smart urban heat planning focuses on demand and resource availability. It combines the end user's thermal comfort and relation between supply and consumption, and tries to satisfy demand through efficient distribution networks and supply systems based on renewable energy and waste heat. From an economic perspective, this makes the combination of district heating and energy-efficient buildings feasible.

In a dynamic energy market, smart buildings connected to district heating could sell their excess energy, cutting down the heat-load peak, allowing the district heating supplier to avoid running peak-load boilers, often fuelled by conventional energy sources. District heating could integrate excess heat (e.g. heat recovery of cooling systems or data centres), heat pumps driven by photovoltaic solar panels, as well as geothermal and solar thermal energy.

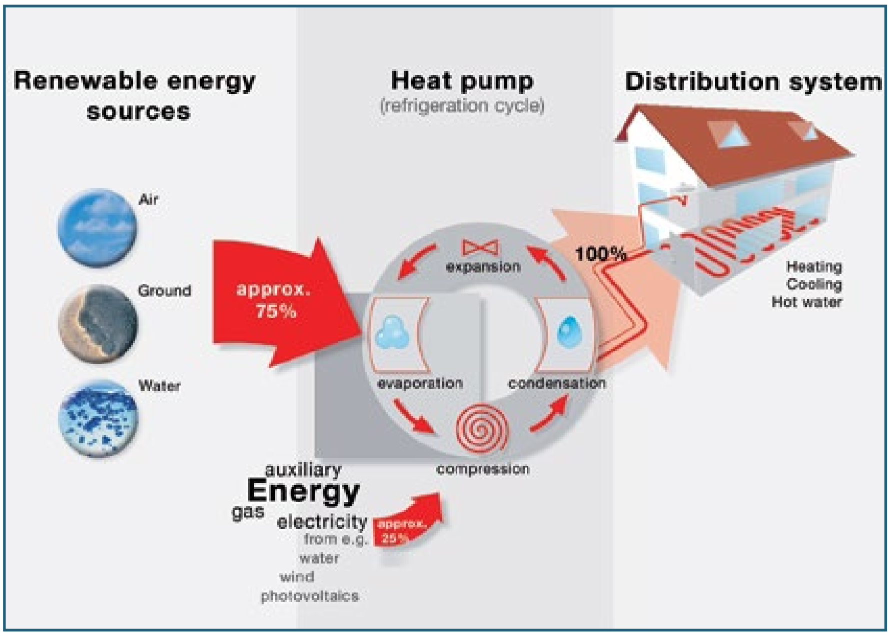
Since 1990, in Denmark, district heating systems have a considerable role in the reduced national CO_2 emissions. District heating is a cornerstone of Denmark's many smart cities (for example, in Sønderborg where it has enabled a greater uptake of renewables and smarter energy use) [31]. District heating was the Danes' answer to the oil crisis from 1973 that affected the then oil-dependent country. In an effort to increase its energy security, the country has since invested heavily in renewables, energy efficiency and district heating. When the oil price later dropped, taxes were increased in order to support more environmental-friendly solutions. Today, most Danes receive their heating from a district heating system [32].

HEAT PUMPS IN FINLAND

Heat pumps transform heat in the air, ground and water to useful heat. They can use waste energy from industrial processes and exhaust air from households. A heat pump system consists of a heat source, the heat pump unit and a distribution system to heat/cool the building. When using electricity and thermal energy from renewable sources, heat pump systems provide a 100%-renewable solution for the heating and cooling of buildings. The use of heat pumps can also be steered towards flexible use and demand response according to grid needs.

Heat pumps have become a popular heating source in Finland. The country's vision is that by 2020 there will be 1 million heat pumps (in a country with a population of 5.4 million) running with an installed capacity of more than 6000MW, generating more than 10TWh of renewable energy annually [33]. Policies to achieve this vision include tax deductions of renovation work (€2000 – €3000 for labour costs) and a subsidy programme of up to 20% when oil and electric-heating systems are replaced by a heat pump, biomass or a district heating system [33].

Figure 12 - Operation principle of a heat pump (Source: Rehva)



AMSTERDAM IS BOOSTING THE ROLL-OUT OF ELECTRIC VEHICLES

More compact, light and efficient batteries, together with a growing political determination to decarbonise the transport system, have advanced the interest of electric vehicles in Europe. Demand response and energy storage systems in buildings can maximise the charging of electric vehicles with renewable energy sources. Smart charging of vehicles can avoid costly spikes in power demand and operate as storage to deliver valuable services to the electricity system.

Electric vehicles are heavily subsidised in the Netherlands, with additional subsidies available in Amsterdam. The Dutch capital has taken an active role in encouraging electric vehicles since 2009, prompted by a desire for cleaner air. Having established 1,500 charging points serving 5,000 users a month, the city is keen to maintain this momentum. Drivers of electric vehicles can also enjoy the benefits of preferential parking permits and exemption from registration taxes [34].

Figure 13 - Electric Vehicle in Amsterdam (Source: ZDNET)

SMART CASE STUDIES

There are numerous examples that demonstrate some or all of the characteristics of a smart building embedded in a local or wider environment. A selection of smart case studies is presented in this chapter.

SMART OFFICE BUILDINGS

The Edge in Amsterdam is a leading example of a smart office building in Europe, demonstrating all of the characteristics of being part of a smart system. The building uses 70% less electricity than comparable office buildings. The roof and the south-facing facade incorporate the largest array of photovoltaic panels compared with other European office buildings, and an aquifer thermal energy storage system provides all of the energy required for heating and cooling. A heat pump is connected to this storage system, significantly increasing efficiency. The building and its users are connected by a smartphone app that can direct users to a parking spot, find them a desk and tweak the environment according to individual preferences for light and temperature, wherever the user goes. The smart design, lighting solutions and the level of connectivity make this office building a leader in the smart building field. [35]

Figure 14 -The Edge building in Amsterdam (Source: Deloitte)

Building 1 in the Swiss city of Basel is another inspiring non-residential building. The intelligent building with a room-automation system makes a considerable contribution to the building's high energy-efficient standards (primary energy requirement of 80.2 kWh/m^2 per annum). Demand-controlled and energy-efficient room automation is ensured in conjunction with presence and light sensors. The system automatically switches off the light, ventilation and heating and cooling when a workstation is not in use. Heat is recovered in a highly-efficient process and a heat pump generates hot water [36].

To ensure that Building 1 maintains, and even continues to improve its high level of energy efficiency, the energy flow is measured and monitored using an energy management system. The building is not just smart and energy efficient, it also ensures the best air quality for its occupants [36]. .

THE STORY PROJECT - RESIDENTIAL STORAGE, LOAD SHIFTING AND FLEXIBILITY

A dozen houses in a residential neighbourhood in Oud-Heverlee, Belgium, are equipped with a range of technologies to provide a maximum of load-shifting potential. They are a mix of old and new houses, with photovoltaic energy generation, solar-thermal energy and heat pumps. Some of the buildings will be equipped with a fuel cell, a battery, or a combination of both. A flexible smart-control system is implemented that will test these different models.

The buildings will all be equipped with advanced monitoring and control systems. One specific building, already equipped with all available smart technologies from smart household appliances to an electric car and advanced controls for ventilation, takes load shifting a step further to provide grid independence for a couple of days. The aim is to demonstrate flexibility and grid balancing across a neighbourhood – results will be available in 2017. [37]

Figure 15 - A seasonal thermal storage tank, which is part of the Story project. The tank will be loaded through a solar thermal collector (Source: Horizon2020 [29])

SMART DISTRICT OF ASPERN – SELF-LEARNING SYSTEMS OPTIMISING ENERGY USE

Aspern, a former airfield in Vienna, Austria, is developing into one of Europe's most modern, multi-functional city districts. The research company, Aspern Smart City Research, is developing and testing state-of-the-art solutions for smart buildings to function as micro-energy hubs, optimising energy use inside and outside the building walls. Their smart building testbed consists of both residential and non-residential buildings and groups many components of a smart-ready built environment: photovoltaic panels, battery and thermal storage, smart meters, solar-thermal, heat pumps and dynamic and self-learning control systems [38].

In order for the buildings to interact with the electricity grid, aggregation levels must be created among several buildings. According to the research company, "at least two systems are required for this purpose. One is located in the building itself, a Building Energy Management System, which calculates the electricity consumption of the building and any flexibility at regular intervals. The other, the Energy Pool Manager, acts as an interface between the individual buildings and the electricity exchange" [38]. The dynamic and self-learning control systems calculate estimated energy requirements (for example, depending on weather conditions) and by doing so improving the energy use. Complex ICT systems facilitate the optimal management of the production, distribution, consumption, storage and transmission of energy within the district [38].

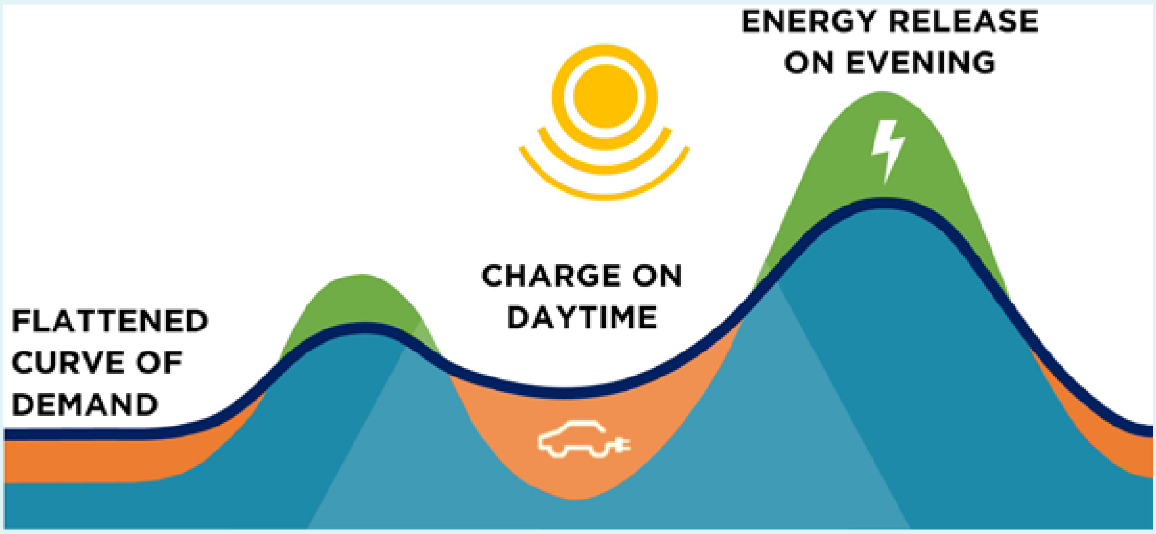
Figure 16 - Smart district of Aspern under construction (Source: Aspern Smart City Research)

CITY-ZEN – THE VIRTUAL POWER PLANT AND VEHICLE2GRID PROJECT

The Virtual Power Plant, as part of the City-Zen project in the Netherlands, aggregates 50 participants into one virtual production and consumption unit. Due to this aggregation, it is possible to trade energy on the wholesale markets. All participants have photovoltaic panels and will integrate a battery. With the battery use, it is possible to store energy during times of low electricity prices and discharge the battery at times of high prices. [39] This project demonstrates how buildings can respond to the need of the grid and enable renewables.

Within the City-Zen project, the Vehicle2Grid project gives a small number of households control over their energy supply with the aim of showing how this can support to better balance the energy system. Residents were able to use the battery in their electric car to store their locally-produced energy and reduce flows with the grid, as well as to unload the stored energy in their batteries to be used locally or fed into the grid. After two years, households reduced their energy exchange with the grid by 45%. This demonstrates how renewables and electric vehicles can be integrated to provide a smart solution for integration with the grid. [40]

Figure 17 – Vehicle2Grid Concept (Source: Amsterdam Vehicle2Grid [32])



SUPERMARKET AND DISTRICT HEATING CONNECTIVITY

Around 20 Danish supermarkets send surplus heat from their refrigeration systems to district heating networks that provide heat to private homes, integrating district heating with the broader energy systems. SuperBrugsen in Høruphav saves more than €25,000 annually on gas and reduces CO_2 emissions by 34% by using the surplus heat from the refrigeration system to supply hot water. With a connection to the district heating network, it can also supply heat to 16 homes annually. The project was inspired by the vision put forward by Sønderborg, a municipality in Denmark, to become zero-carbon by 2029. [41]

Figure 18 – Superbrugsen in Denmark (Source: Danfoss [33])

ENERGY STORAGE AND EFFICIENCY FOR A SMART HOTEL

The Crowne Plaza Copenhagen Towers has 77% lower electricity consumption than comparable hotels operating conventional energy technology (as of 2015). The hotel's heating and cooling systems are highly energy efficient using an advanced Aquifer Thermal Energy Storage (ATES) system. The consumption for central systems for heating, air conditioning and ventilation is only 51 kWh/m^2 per annum[10].

The ATES system covers up to 60% of the building's total cooling needs. The cold groundwater circulates through an exchanger that cools water in the hotel's hydronic air conditioning system. In this process, the groundwater heats up and is stored in another well, so that it can be used during the winter for room heating. The heating, ventilation and air conditioning pumps are very energy efficient and equipped with frequency converters to enable them to adapt to variations in flow requirements – contributing further to energy savings [42].

Figure 19 - Crown Plaza Copenhagen Towers (Source: Hotel-R)

[10] For an average European 4-star hotel, the energy consumption is about 300 kWh/m2 – although this includes devices connected to plugs, which is not included in the figure of this hotel.

INTELLIGENT FAÇADE

The EU-funded Multifunctional Energy Efficient Façade System for Building Retrofitting across Europe (MeeFS) project, launched in 2012, has developed an innovative, energy efficient, multifunctional façade system for retrofitting geared towards the residential building sector. The concept idea of MeeFS is based on efficiency and on a multifunctional integrated façade system. It is an innovative concept for retrofitting which applies multifunctional energy efficient panels and technological modules, as well as innovative composite façade structure materials, all easily integrated in the façade for building envelope retrofitting.

The 'smart' aspect of this innovative solution consists of a small processor within the façade, which can be connected to the building's energy management system, which enables full automation and monitoring of energy consumption. "The intelligent system developed within the framework of the MeeFs project, will control and monitor the technological units of the façade energy consumption, as well as relevant factors, including sun orientation for photovoltaic units and water feeding for organic green components" [43]. This and similar projects are illustrating how smart building elements can be connected and interoperated in an energy optimising way.

Figure 20 – Smart facades in Merida in Spain (Source: MEEFS Facade concept [35], 2015)

CONCLUSION

Buildings are an integral and elementary part of Europe's energy system and will play a pivotal role in the transition to a smart decarbonised economy. However, as this report shows, the European building stock is currently far from being smart-ready - all countries have to take major steps in order to effectively facilitate this transformation.

The European Commission has proposed a *smartness indicator*, to be developed in the coming years, to rate the technological readiness of a building to interact with its occupants and the grid and to manage performance efficiently [44]. According to the Commission, the indicator should cover:

Features which enhance the ability of building occupants and the building itself to react to comfort of operational requirements, take part in demand response and contribute to the smooth and safe operation of various energy systems and district infrastructures to which the building is connected.
Proposal for a revised energy performance of buildings Directive, European Commission. Brussels, 30.11.2016 [45]

While this is a crucial step in the right direction, Europe has some way to go towards reaching a smart building stock. The smartness indicator must not only assess the current situation, but be enhanced to lead Europe towards a smart and decarbonised building stock by 2050.

For buildings to be able to wield their potential -empowering occupants to control their own renewable-energy production and consumption, cut energy bills, facilitate a surge of renewable energy, support the uptake of electrical vehicles and facilitate better living and workplaces – they must first and foremost be energy efficient.

Despite various good examples and some progressive national legislative measures paving the way for a smarter building stock, current EU legislation lacks sufficiently ambitious drivers to push the development of smart buildings. However, the revision of EU legislation on the energy performance of buildings, energy efficiency, the electricity market, and renewable energy is a good opportunity to make significant steps forward and recognise the role of buildings in the energy system.

A smart building revolution is not just about upgrading our building stock, mitigating emissions or balancing energy flows, it is about delivering direct benefits for EU citizens in terms of lower energy bills and warmer homes, and wider benefits for Europe as a whole with jobs created and boosts to economic growth.

KEY TAKEAWAYS FROM THIS REPORT

- All EU Member States must ensure that their building stock, energy infrastructure and regulatory and financial framework are future-proof, in order to reap the benefits of the pending smart building revolution.

- 'Smart infrastructure' is not yet in place. Only three countries, Sweden, Finland and Italy, have completed their deployment of smart meters, with nearly all consumers equipped with smart meters.

- The leading countries in terms of a smart-ready built environment (Sweden, Finland, Denmark and the Netherlands) have implemented progressive and holistic approaches to decarbonise the energy system, including taxes, subsidies and stringent building regulations.

- Several case studies illustrate the importance of dynamic and self-learning control systems, which empower occupants with control over their own energy consumption and production. Today, these systems play an insignificant role in the residential building sector, but the importance of this technology is set to grow quickly.

- Adaptive solutions - such as demand response - are only in their infancy, especially in the residential and commercial sectors. Only three countries (Finland, France and the United Kingdom) have a commercially-open demand response market.

- Data quality and availability of smart building indicators (such as dynamic and self-learning control systems) are currently not adequate to foster an optimal science-based development in this sector.

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ISBN 978-94-91143-18-2