How ready is Europe for the smart building revolution?

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Abstract

With an appropriate framework, buildings could play a central role in transforming the EU energy system, increasing the speed with which the three biggest CO_2 polluters – the building, transport and power sectors - are reducing their climate impact. Buildings are entering a transition phase, transforming into highly efficient micro energy-hubs consuming, producing, storing and supplying energy, making the system more flexible and efficient enabling a rapid uptake of renewable energy and electric vehicles.

The increased portion of decentralised renewable energy systems - key to achieve a sustainable and decarbonised energy system - causes variable stress on the grid. The growing number of electric vehicles, together with a bigger share of electrical heating of buildings, will challenge the energy system even further. These tendencies highlight the need for the implementation of strategies integrating smart buildings and electric vehicles to avoid a system overload.

This paper provides an answer to the question, *what role can smart buildings play in the future energy system?,* by presenting ten interrelated principles. Apart from principle 1, maximising the building's energy efficiency, which should be applied first, the sequence of the nine remaining principles is not laid out in order of importance. They are all important separately, but more effective considered in a holistic approach to fully achieve decarbonised transition pathways. Building further on these principles, the extent to which the Member States of the European Union are ready for the transition to a smart building stock is assessed and evaluated.

The purpose of this paper is to inspire policy-makers of how to foster the potential of buildings as "all-in-one" entities that could benefit the energy system and empower the end-users.

Introduction

The building stock and the energy systems are at the initial stages of a journey to being smart: moving from a centralised, fossil fuel-based and highly energy consuming system towards one that is efficient, decentralised, automated, consumer-focused and powered by renewable energy. With the Paris Agreement, the world's countries agreed to limit global warming to below 2 °C, which implied a renewed emphasis on the need for Europe to accelerate the smart energy transition.

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 demonstrating the multiple characteristics and plausible benefits of a smart built environment. While these preparatory and inspiring steps are crucial ones, an intensification is needed. This means a change of mind-set, to recognise buildings as an integral and active part of Europe's energy infrastructure and fully explore their wide-ranging abilities.

The current approach of European legislation does not go far enough to encourage smart buildings, only promoting the im-

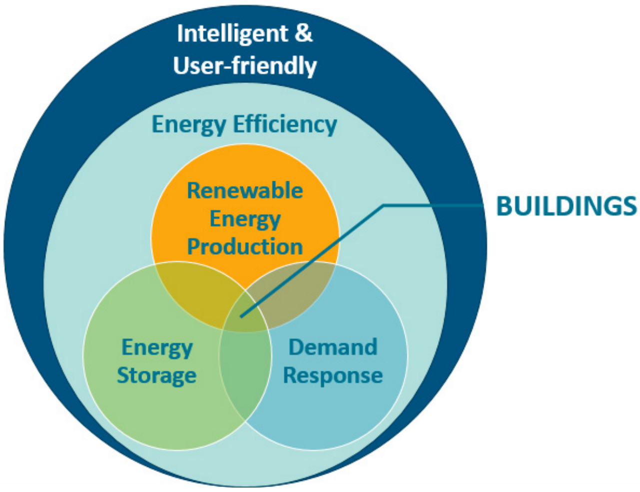

Figure 1. Buildings flexibly connected and synchronised with an energy system (Source: BPIE).

plementation 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 truly push forward the advances needed and to overcome barriers to enabling smart buildings. The ongoing review and revision 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.

BPIE has developed ten principles for buildings to work as micro energy-hubs and to be at the core of a decarbonised and decentralised energy system [1]. Building further on these principles, this paper also assesses the extent to which Member States across Europe are ready for the transition to a highly efficient and smart building stock. It considers whether buildings are efficient and healthy, whether they optimise and control use of resources, and whether they respond to the needs of the energy system and enable renewable energy.

The transition towards micro energy-hub

Several case studies have demonstrated that by viewing buildings as stand-alone units using energy supplied in various forms, we are overlooking a huge opportunity. With the appropriate support, buildings could play a leading role in transforming the EU energy system increasing the speed with which the three biggest CO_2 polluters – the buildings, transport and power sectors – are reducing their climate impact.

A micro energy-hub can be considered as a building or a group of buildings flexibly connected and synchronised with an energy system, being able to produce, control, store and/or consume energy efficiently. Energy can be saved, generated, stored and used where people spend most of their time – in buildings. This paper does not intend to emphasise one specific energy carrier, it is about the convergence, alignment and synchronisation between heat and electricity. Both are essential and can be produced in a sustainable way, as well as being stored and transported in and around buildings.

Ten principles of buildings to function as micro energy-hubs

Ten interrelated principles have been drawn from an understanding of how buildings can effectively function as micro energy-hubs. They are all important separately, but most effectively considered together. Apart from principle 1, which should be applied first, the sequence of the nine remaining principles is not laid out in order of importance. All the principles below must be in place to fully achieve the optimal transformation of the energy system.

PRINCIPLE 1 – MAXIMISE THE BUILDINGS' ENERGY EFFICIENCY FIRST

Energy efficiency and demand flexibility1 measures are fully complementary. Thus, switching focus from energy efficiency to energy flexibility is not desirable, unless the energy efficiency potential is fully exploited first. A deep energy renovation of the existing building stock could reduce energy demand by 80 % before 2050 compared to 2005 levels. A highly energy efficient building stock, realised by deep renovation and efficient new buildings, brings multiple benefits for demand reduction, but will also enable demand response and the integration of volatile renewable energy increase on the supply side. [2]

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 preheating or precooling, allowing energy consumption shifts to other time periods.

Since the real potential of demand response lies in thermal applications, the trend of heat pumps' market uptake leading to a significant increase in electricity demand highlights the potential, but at the same time the need of the building stock to better interact with the grid. A shift from boilers with conventional fuels to electrically-driven heating systems could induce a significant increase in peak electricity demand. Demand response could compensate for this peak, for which heat pumps with lower capacity are more appropriate.[2] Furthermore, heat pumps achieve their most optimal performance[3] in buildings with lower heating demand, highlighting once more the importance of energy efficient buildings.

PRINCIPLE 2 – INCREASE ON-SITE OR NEARBY RES PRODUCTION AND SELF-CONSUMPTION

The EU's framework on climate targets and buildings' performance requirements is driving new buildings towards a nearly zero-energy level, integrating small-scale renewable energy systems. On-site or nearby-building installed technologies, such as heat pumps, biomass boilers, photovoltaic and solar thermal panels are becoming mainstream.

1. Instead of steering the supply side with energy generation to balance the grid, demand flexibility steers the energy demand of end-users using price signals (see principle 3).

2. This happens as: 1) managing peak-shaving in a larger multi-use building is more complex and 2) the electricity load can only be shifted for a limited number of hours. If a significant number of heat pumps perform this shift, the hours before the peak might become ''saturated''. When it occurs, there is no other option than to increase consumption during these hours.

3. Seasonal performance factor.

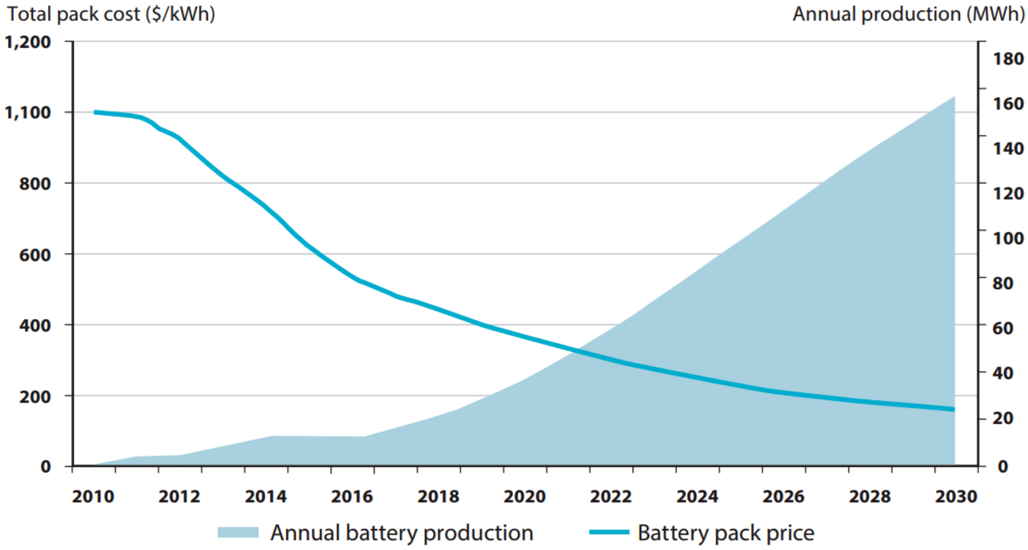

Figure 2. Lithium-ion battery pack cost and production, 2010-2030 (Source: Bloomberg New Energy Finance).

Even at a time with a very low oil price, the Deutsche Bank is expecting solar electricity to become competitive with retail electricity (i.e. grid parity) [3] in an increasing number of global markets, due to declining solar panel costs as well as improving financing-and-customer-acquisition costs.[4]

Despite the previsions on grid parity and the fact that the Energy Performance of Buildings [4] and the Renewable Energy [5] Directives have to a certain extent stimulated the deployment of on-site renewable energy systems, the on-site (or nearby) renewable energy production and self-consumption are far from their full potential.

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. It does not just help end-users to limit their energy consumption, it empowers them to better control their own energy system, increasing the level of grid security. Encouraging self-consumption will drive energy suppliers to become more agile and innovative to faster reach a balanced level of centralised and decentralised production.

In a dynamic energy market, end-users connected to district heating could even 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 heat delivered by 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.

4. In 2015, the European solar power market grew by 15 % year on year (mainly in 3 countries – the UK, Germany and France), while globally there was a market growth of over 25 %. The European heat pumps market grew slightly over the past years, but future volume sales are expected to grow rapidly, driving a power-load growth of heating demand.

PRINCIPLE 3 – STIMULATE ENERGY-STORAGE CAPACITIES IN BUILDINGS

In an energy environment of increased complexity, technologies that can rapidly adapt to operating loads, that absorb or release energy when needed or convert a specific final energy into another form of energy, will become vital.

Building energy storage is developing fast and companies as well as innovators around the world are in fierce competition, creating a revolution towards more consumer-driven storage. Economies of scale are leading to a significant cost decrease of home battery systems, demonstrated by the forecast of the World Energy Council (see Figure 2), arguing that the cost of batteries for large-scale energy storage could drop by 70 % over the next 15 years.

Battery-based projects are likely to account for an important part of future building-related storage investments, but other storage-technology options, such as thermal and hydrogen storage, must be considered as well.

Domestic hot water storage is a well-known technology, often combined with solar thermal panels. Despite very low costs, the storage of heat or cold in the building mass – i.e. walls and ceilings – is a less common technology with a practically untapped potential. A more innovative technique is the application of construction material with integrated 'phase-change materials', which can store heat or cold 'latently' by using a process that occurs at a defined temperature level. The storage of both thermal and electrical energy could balance daily-and-seasonally[5]-varying energy supply and demand, and would lead to a reduction of expensive peak-energy-supply. Storage possibilities will facilitate change in consumption over time, through load shifting and peak shavings. By making the best use of renewable energy, storage can make the energy system more cost-effective

5. Seasonal storage technologies are currently very limited and far from common practice, but potentially have an important role to shift seasonal (winter) peaks.

PRINCIPLE 4 – INCORPORATE DEMAND RESPONSE CAPACITY IN THE BUILDING STOCK

Demand response is the ability to shift energy demand by reducing peak consumption and avoiding grid imbalance[6]. It can be more cost-effective to apply demand response than increasing the grid infrastructure to meet demand. Instead of steering the supply side with fluctuating energy generation to balance the grid, demand response steers the energy demand of end-users by using price signals to rearrange their consumption.

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-usage temporarily without a change in consumption during other periods (e.g. lower the indoor temperature), shifting energy demand to other time periods (e.g. start cooling a building before peak period) or temporarily using on-site generation instead of energy from the grid (e.g. micro-cogeneration with renewable energy sources).

The EU demand response market is still in its infant stage. Only a few demand response service providers exist, and in most EU Member States, only the largest industrial end-users, with their own bilateral power purchasing agreements, can participate in demand response programmes. [6] Demand response in Europe's commercial and residential buildings is hardly applied, but steps in this direction are already being taken with the development of new apps allowing end-users to check on the status and to take control of their home appliances, enabling technologies for demand response with a simple touch on their smart phones.

Mass demand response will only happen if companies or organisations act on behalf of consumers, extracting value from pooling resources (principle 8), enabled by dynamic pricing incentivising smarter energy use (principle 7).

PRINCIPLE 5 – DECARBONISE THE HEATING AND COOLING ENERGY FOR BUILDINGS

Buildings' heating and cooling consume a big share of EU's energy and relies with a share of 75 % still largely on fossil fuels as its dominant energy source. It is a cause of concern that almost half of the EU building stock has inefficient individual boilers installed before 1992 [7]. Decarbonisation is fundamental for the transition to a low-carbon economy, and therefore synergies between the heating and electrical systems should be exploited and utilised. Phasing out these inefficient boilers using conventional fuel and encouraging low-carbon systems such as heat pumps and district heating on renewable sources is feasible, but it has to be undertaken within a strategic framework to avoid lock-in effects and stranded assets.

Building owners and construction professionals' reluctance and limited knowledge that enables smart and foresighted planning is a major challenge to overcome. Replacement of old heating systems are often made under time pressure (e.g. in case of a sudden failure) and the complex stream or lack of a reliable and easy-to-understand information source makes it hard for building owners to make the right choice. This leads to end-users making an unsustainable choice while the window of opportunity closes for years.

6. Grid imbalance possibly caused by significant penetration of decentralised – and mostly intermittent – renewable energy and transition to electrification of heating-systems and vehicles.

PRINCIPLE 6 – EMPOWER END-USERS VIA SMART METERS AND CONTROLS

New technologies, continuous monitoring the energy streams and the technical building systems, can provide the end-user valuable information on the actual performance of their building (e.g. saved, produced and shifted energy and related financial gains) as well as notifying the user on aspects such as unusual consumption patterns, technical defects and needed maintenance.

Smart meters can empower end-users by enabling them to have a better understanding and control over their energy system. Accurate measurement of the energy consumption to provide real-time data on the energy used is at the same time a requirement to valorise demand response services. Without smart meters allowing end-user to be compensated for the savings achieved during demand response actions, the market will lose its main incentive, and it may impede the full deployment of demand response.

Smart controls of heating and cooling and household appliances empower building users to modulate their energy use (manually or automatically), considering their preferences, needed load and price signals, enabling a more efficient use of energy and mitigating the peaks of the grid. However, if there is no dynamic price signal automatically coming from the grid to activate or deactivate these applications, demand response solutions for buildings will not take off.

PRINCIPLE 7 – MAKE DYNAMIC PRICE SIGNALS AVAILABLE FOR ALL CONSUMERS

Thanks to technological advances, time-varying pricing is now a possible path which would lead to a smarter use of the grid and its available renewable energy and ease peak loads. The availability of dynamic price signals for industrial, commercial and residential consumers is a requirement for the uptake of demand response solutions in buildings. Current tariffs applied to dynamic pricing are not reaching their potential impact because the differences in price setting are too low to incentivise demand response.

A flat electricity rate might be appealing due to its simplicity, but in reality the customers who tend to use electricity during off-peak times, when prices are cheaper, are essentially subsidising those who primarily power their appliances with the most expensive peak electricity.

The development of decentralised power storage capacity and self-consumption of renewable energy would also be boosted through dynamic pricing. It would incentivise to store energy when the price is low – making power storage more beneficial. A reduction in demand during high-priced hours could reduce wholesale market prices in those hours, which would be a benefit not only to those providing demand response services, but to all society.

PRINCIPLE 8 – FOSTER BUSINESS MODELS AGGREGATING MICRO ENERGY-HUBS

Transforming Europe's energy system and the building stock cannot be funded only by public money. An effective way to channel private investments is to encourage new third-partydriven business models, aggregating services to benefit economies of scale. These aggregators - think Uber or Airbnb - are already entering the energy market, but for investors it is still an unclear and wobbly path.

Since the direct gains per individual consumer are limited, mass demand response requires aggregators to act on behalf of end-users. The viability of these business cases depends on the economy of scale they can operate in – their ability to pool sufficient resources – and on the end-user's willingness to participate. The provided services have to be user-friendly and deliver clear added value for the customer to hand-over control.

Aggregators can extract value from a pool of resources though smart technological solutions, using smart meters and the access to real-time consumption data (principle 6). The absence of smart meters or the lack of data access will block the uptake of aggregator-driven business models and therefore the uptake of demand response from the building stock.

PRINCIPLE 9 – BUILD SMART AND INTERCONNECTED DISTRICTS

Buildings are the key construction components of urban areas: smartening and interconnecting them within a district perspective can generate real value to the entire society. Enhanced energy efficiency, interaction with clean mobility, uptake of locally-produced renewable-energy sources, resilience to shocks in demand and supply and a boost for the economy are some of the possible benefits from uniting buildings within districts.

Smart districts will play a key part in the transition to a sustainable energy system. Demand for heat and cooling in urban areas is steadily growing in European cities. Smart district energy solutions can use better primary energy flows than the old system, integrate cost-effectively renewable energy sources into the heating and cooling sectors. Furthermore, smart districts create leeway for electric vehicles to enter urban areas with force. Buildings can bring renewable electricity directly – potentially using decentralised storage at building or district level – to the growing fleet of electric vehicles.

PRINCIPLE 10 – BUILDING INFRASTRUCTURE TO DRIVE FURTHER MARKET UPTAKE OF ELECTRIC VEHICLES

A more decarbonised mobility sector is crucial for Europe to meet its climate and energy goal and will enhance air quality and mitigate greenhouse gas emissions. The inherent benefits of smart buildings should be used to speed-up this transition.

Electric vehicles are on the rise on the European market. In Norway, for example, almost one quarter of the new vehicles sold today run on electricity and politicians from both sides of the political spectrum have reached concrete decisions to have 100 % of the new Norwegian cars running on green energy by 2025. [8] This is not just buildings getting smarter, but cars and their charging stations too. Smart charging avoids costly spikes in power demand and can operate as storage to deliver valuable services to the electricity system. 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. If the consumers' uptake is supported with incentives, the whole society will reap benefits.

Most charging time of electric vehicles takes place at home and at the workplace, making buildings gradually become docking stations – modern gas stations – providing renewable electricity instead of fossil fuels.

An additional consequence of the spread of electric cars is the higher demand for lithium-ion batteries, the main technology for storage devices (principle 3) attached to utility grids and rooftop solar units. This is allowing manufacturers to scale up production and slash costs [9].

Mapping a smart-ready built environment

There are several barriers policy-makers must overcome in order to successfully carry out the ten principles. In many countries, a rigid regulatory framework and other legislative obstacles hinder new business models and market developments. This is especially true for demand response activities, for which most European markets remain closed. Financial insecurity is another key barrier, where new business models are impractical because of low energy prices and wholesale energy pricing. Member States should therefore design and implement a regulatory and financial framework that fosters development and innovation within the building sector, utilizing synergies with the energy and transport sectors. This section evaluates how ready the Member States are for the smart building transition.

A smart-ready built environment, comprising the ten principles, takes advantage of the full potential of ICT and electronic systems to adapt its operation to the needs of the occupant, improve its energy performance, and interact with the grid. Smart buildings can play a leading role in transforming the EU energy market, while at the same time facilitate better living and working environment for the occupants. To map whether Europe is ready for the smart building revolution, some key features of what a smart-ready built environment comprises needs to be outlined.

These requirements have been drawn from the ten principles. The categories below do not indicate 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 catalyses the building stock into becoming 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, a smart-ready built environment requires **efficient and healthy buildings**. The basic need of most occupants is to have a healthy and affordable home. 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.

A smart built environment empowers the occupant with information and control of the energy flows through **dynamic operability,** through connected technical building systems and other appliances inside the building (for example, smart meters, thermostats and refrigerators, as well as security and access-related systems). The buildings are self-adaptive, through dynamic and self-learning control systems, optimising the various interactions and energy uses.

A smart built environment requires **energy system responsive buildings**, ready to respond to the needs of the electricity,

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

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

Figure 3. Smart-Ready Built Environment Indicators (Source: BPIE own analysis).

district heating and cooling grids and the broader energy system, for example, in the case of peak loads. Buildings could play a key role in balancing the grid and enabling wider uptake of electric vehicles. 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 provision of the building stock's energy requirements. Buildings can facilitate greater uptake of renewables in many ways, such as self-production (for example, photovoltaics, solar thermal, biomass or geothermal) or by inter-operating in a smart district where several buildings optimise the use of larger renewable energy systems (for example, through a district heating system on biomass or using waste heat).

METHODOLOGY

In an effort to map the smart-ready level of the built environment in the 28 EU Member States, 15 indicators have been defined. These indicators have been selected based on the ten principles of a smart built environment as outlined above. Mirroring the smart built environment, the indicators are heterogeneous and interdependent.

The selection of data underpinning the indicators has to some extent been affected by data scarcity. For example, an alternative data source for 'Building energy performance' would be an EU Energy Performance Certificate database, but this does not currently exist on European level. Due to the limited market penetration of dynamic and self-learning control systems, especially in the residential sector, no reliable or comparable data is available either. Future versions of this mapping exercise should aim to include these aspects.

Table 1. Indicator scoring for the Smart-Ready Built Environment (Source: BPIE own analysis).

BUILDING ENVELOPE		FINAL ENERGY CONSUMPTION		ABILITY TO KEEP ADEQUATELY WARM/COOL	
Score	U-value	Score	kWh/m2	Score	Share (%)
5	<0.29	5	<50	5	>99
4	0.29 - 0.80	4	50 - 115	4	93 - 99
3	0.81 - 1.30	3	116 - 182	3	87 - 92
2	1.30 - 180	2	183 - 248	2	81 -86
1	>1.80	1	>248	1	<81
HEALTHY LIVING AND WORKING ENVIRONMENT		**SMART METER DEPLOYMENT**		**CONNECTIVITY**	
Score	Share (%)	Score	Share (%)	Score	Score (%)
5	>99	5	>99	5	>99
4	93 - 99	4	50 - 99	4	90 - 99
3	87 - 92	3	25 - 49	3	80 - 89
2	81 -86	2	1 - 24	2	70 - 79
1	<81	1	<1	1	<70
DYNAMIC PRICING		**FLEXIBLE MARKET**		**DEMAND RESPONSE**	
Score	Evaluation of electricity market	Score	Score (%)	Score	Evaluation of market
5	Fully dynamic pricing	5	>90	5	Commercially open
4	Hourly pricing (for majority of user)	4	75 - 90	4	Open for majority of actors
3	Hourly pricing (for minority of user)	3	60 - 74	3	Open only for major industries/actors
2	Static Time of Use pricing	2	45 - 59	2	Very low participation
1	Fixed pricing	1	<45	1	Closed
BUILDING ENERGY STORAGE		**ELECTRIC VEHICLES**		**RENEWABLE ENERGY**	
Score	Share of dwellings (%)	Score	Share of EV (%) of new car registrations	Score	Share of energy from RES (%)
5	>3	5	>75	5	>50
4	1 - 3	4	50 - 75	4	38 - 50
3	0,1 - 0.99	3	25 - 49	3	25 - 49
2	0,001 - 0.099	2	10 - 24	2	10 - 24
1	<0,001	1	<10	1	<10
PHOTOVOLTAICS		**HEAT PUMPS**		**DISTRICT HEATING**	
Score	(Share of total energy consumption %)	Score	Share (%)	Score	Share (%)
5	>8	5	>6.50	5	>50
4	6 - 8	4	4.01 - 6.50	4	34 - 50
3	3 - 5	3	1.51 - 4.00	3	18 - 33
2	1 - 2	2	0.10 - 1.50	2	1 - 17
1	<1	1	<0.10	1	<1

Figure 3 and Table 1 the indicators used to calculate the smart-ready level of the built environment. 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 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[7] [10] and Eurostat [11] [12] [13] [14]. Other sources include the Smart Energy Demand Coalition (SEDC) [6], the European Commission's Joint Research Centre (JRC) [15] [16], European Commission's DG Energy [17], the International Energy Agency (IEA) [18], the Agency for the Cooperation of Energy Regulators (ACER) [19], OECD [20], German KfW [21] and the European Automobile Manufacturers Association (ACEA) [22].

IS EUROPE READY FOR THE SMART BUILDINGS REVOLUTION?

Figure 4 answers the question "is the European built environment smart-ready?" with a clear "no". Sweden, Finland Denmark and The Netherlands are in the lead, which is due to progressive policies such as smart meter roll-out and investments in renewable energy. The four countries also have a long history of ambitious building regulations. But even these countries have room for improvements, with rather closed markets for demand response and little market penetration of electric vehicles and building energy storage capacity.

Table 2 shows the underlying indicators and their respective scores. 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. 'Building performance', 'dynamic market' and 'efficient heating & cooling capacity' are all valued through two sub-variables (see calculation in Figure 4).

Most of the slow-starters score low on all the indicators except final energy consumption, 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.

Table 2 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 aggregated score. However, interest in

7. The EU Building Stock Observatory is a newly launched initiative by the European Commission – an online data portal for the European building stock and related key policies.

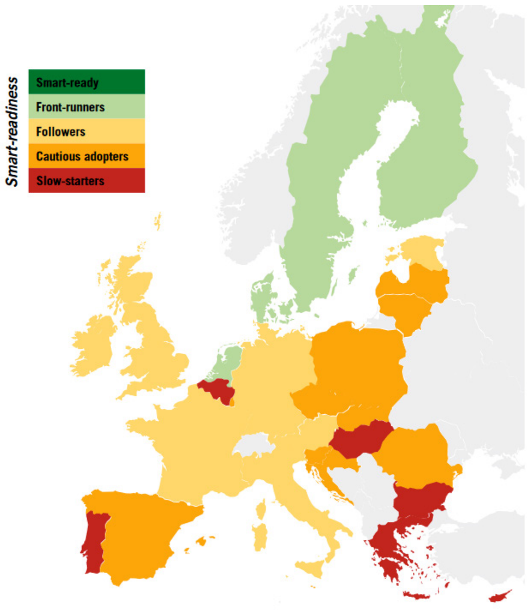

Figure 4. Buildings' smart-readiness across Europe. Sources and calculation: see Table 1.

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.

Conclusions

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 built environment is currently far from being smart-ready – all countries should take major steps to effectively facilitate a smooth and cost-effective 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 its performance efficiently [23]. The indicator should cover: "Features which enhance the ability of building occupants and the building itself to react to comfort

Table 2. Table of results indicating the smart readiness of the built environment across EU member states.

SMART-READINESS	PHOTOVOLTAICS	RENEWABLE ENERGY	EFFICIENT HEATING CAPACITY		ELECTRIC VEHICLES	BUILDING ENERGY STORAGE	DEMAND RESPONSE	CONNECTIVITY	DYNAMIC MARKET		SMART METER DEPLOYMENT	ABILITY TO KEEP ADEQUATELY WARM/COOL	HEALTHY LIVING & WORKING ENVIRONMENT	BUILDING PERFORMANCE	
			Heat pumps	District heating					Dynamic pricing	Flexibility in the market				Final Energy Consumption	Building Envelope (U-value)
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	○	○	○	○	○	○	○	○	○	○	○	○	○	◕	○

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 is the building is connected." [24] This is an important step but the indicator needs to be further developed and concretized, yet dynamic and open for new technologies and processes.

KEY TAKEAWAYS FROM THIS PAPER

- 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.
- 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.

Despite various good examples and some progressive national legislative measures paving the way for a smarter building stock, current EU and national legislations lack 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 that is currently taking place is a window of opportunity to make significant steps forward and recognise the active role of buildings in the energy system.

A smart building revolution is not just about transforming 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 with jobs created and boosts to economic growth. Policy-makers need to step up and create a suitable framework for this transformation, in order to make the best of this opportunity.

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