European Commission

THEMATIC RESEARCH SUMMARY

Energy Efficiency in Buildings

Manuscript completed in July 2014

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This publication was produced by the Energy Research Knowledge Centre (ERKC), funded by the European Commission, to support its Information System for the Strategic Energy Technology Plan (SETIS). It represents the consortium's views on the subject matter. These views have not been adopted or approved by the European Commission and should not be taken as a statement of the views of the European Commission.

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setis.ec.europa.eu/energy-research

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Executive Summary

Key messages

Buildings are the largest energy-consuming sector in the world, accounting for over one third of all carbon emissions. 75–90% of OECD building stock will still be in service by 2050. Yet the performance of most existing buildings is below current standards. Energy efficiency in buildings is a key focus in European and global climate and energy policies.

This TRS aims to deliver a structured overview of research activities in this sector. Several results have arisen from R&D on ***cost-effectiveness*** *and* ***reliability*** *of products and techniques, and from RD&D of "low-energy" and "nearly zero-energy" buildings for penetration in the market.*

Although progress is being made, ***deep renovation*** *remains a priority if the potential for substantial savings and multiple related benefits is to be realised. A new approach to* ***energy system integration*** *and the extension of the research at* ***district and community levels*** *(taking in social, ICT, health and environmental issues) have started but still require supplementary developments.*

In this context ***storage*** *is assuming a growing role in boosting energy efficiency, integrating renewable energy sources (RESs) and promoting interoperability between systems. The connections between individual buildings and district energy systems should be increasingly strengthened and the potential for flexibility in buildings within smart grids demonstrated, resulting in reduced energy consumption and lower CO2 emissions.*

Computational tools *are necessary to take account of the complexity of buildings during design, assessment and operation. These should be supported by a series of targeted* ***tools and solutions enabling better decision-making****, plus education and awareness on available innovative techniques.*

The present Thematic Research Summary (TRS) provides an overview of RD&D on energy efficiency in buildings, based on recent research project results. The first part of the TRS includes a brief analysis of the scope of the theme and summarises the main policy developments at EU level.

The focus in this publication is RD&D and innovation related to energy efficiency in all types of buildings – new and existing, residential and non-residential. We include the first results from energy systems integration (mostly focused on integrated design), both in individual buildings and at district scale.

About 40% of final energy consumption in the EU is accounted for by the building sector (households and services). At present, nearly two thirds of the energy consumed in buildings is used for space conditioning, while the remaining one third is mostly in the form of electricity used for installations and appliances.

The current trend in Europe is that thermal energy needs are decreasing, mostly due to energy-saving policies, while electricity consumption is increasing, due to the increased use of cooling and electrical appliances. The EU building sector has seen a gradual shift from fossil fuels to renewable energy (RES). In 2010, the share of RES

for end-use energy in the building sector was 11.6%; this percentage has more than doubled in 10 years.

Integrating technological developments and learning curves related to energy efficiency in buildings can contribute significantly to achieving climate and energy targets (IEA 2014).[3] Available technologies already offer great potential to increase energy efficiency in buildings. Several EU demonstration projects, for instance, have proved that existing technologies could significantly improve energy performance in both new and renovated buildings.

Technological RD&D on energy efficiency in buildings reflects our changing approach to producing and consuming energy. Advances have been made in new materials and components, the deployment of new technologies, such as carbon capture and energy storage, integration of renewable energy, assessment and planning methods, and the prediction, monitoring and management of energy performance through ICT.

Energy systems integration at district scale, and interaction between buildings and the various energy networks, has begun both for building retrofits and new construction. However, the building process remains complex, characterised by a high degree of fragmentation and a multitude of stakeholders. From the very start of a project through to the operation and maintenance phases, system efficiency therefore remains an RD&D priority, though the integrated design approach has produced some advances.

Nevertheless, innovation should go beyond purely technological considerations. Innovative approaches, involving environmental, economic, social and behavioural aspects, are under way. This TRS therefore also discusses non-technological innovation as an essential condition for the deployment of technical R&D results, thanks to its ability to help remove persistent structural (regulation, education), financial and market barriers.

The projects selected for this publication, developed mainly under the FP7 PPP EeB, CIP IEE 2007–13 and IEA ETN programmes, delivered, implemented and optimised building and district concepts that **have the technical and economic potential drastically to reduce energy consumption and decrease CO2 emissions**. They address societal challenges in relation to both new buildings and the renovation of existing buildings.

Research results are evidenced through the development of technologies (including materials, products and processes), methodologies (prediction and calculation, assessment, management and control), and the use of new ICT in:

[3] According to the IEA, 42% of the greenhouse gas emissions reduction required to limit the global average temperature increase to 2 °C is attributable to increased energy efficiency. Energy efficiency in the building sector is a priority at international and European levels.

- energy saving and energy efficiency (combined measures to optimise the interaction of the building and its technical systems);
- use of renewable energy sources (solar, wind, etc.) to provide the remaining energy needs;
- energy storage for energy systems integration and to match the supply and demand of the system's components.

In this TRS we use the following definitions:

Energy efficiency means the ratio of the output of performance, service, goods or energy, to the input of energy [Source: Energy Efficiency Directive 2012/27/EU]. Something is more energy-efficient if it delivers more services for the same energy input, or the same services for less energy input. [Source: IEA Glossary].

Energy efficiency improvement means an increase in energy efficiency as a result of technological, behavioural and/or economic changes. [Source: Energy Efficiency Directive 2012/27/EU].

Energy savings is the amount of saved energy, normalised for external conditions that affect energy consumption. The saving is determined by measuring and/or estimating energy consumption before and after implementation of one or more energy efficiency improvement measures. [Source: Energy Efficiency Directive 2012/27/EU].

System efficiency relates to new strategies and models at the planning, decision, and technology levels, agreed by several actors and, therefore, entailing integration and optimisation of energy systems.

An **integrated design approach** requires that the primary stakeholders of a building are involved in the entire design process and continue to provide input through the construction phase, so that all the objectives set for the building are met. [Source: WGBC]

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1 Introduction

This publication has been produced as part of the activities of the ERKC (Energy Research Knowledge Centre), funded by the European Commission to support its Strategic Energy Technologies Information System (SETIS).

The ERKC collects, organises and analyses validated, referenced information on energy research programmes and projects, including results and analyses from across the EU and beyond. Access to energy research knowledge is vastly improved through the ERKC, allowing it to be exploited in a timely manner and used all over the EU, thus also increasing the pace of further innovation. The ERKC therefore has a key role in gathering and analysing data to monitor progress towards the objectives of the European Strategic Energy Technology Plan (SET-Plan). It also brings important added value to the monitoring data by analysing trends in energy research at national and European levels and deriving thematic analyses and policy recommendations from the aggregated project results.

The approach to assessing and disseminating energy research results used by the ERKC team includes the following three levels of analysis:

- **Project analysis**, providing information on research background, objectives, results, and technical and policy implications on a project-by-project basis;
- **Thematic analysis**, which pools research findings according to a classification scheme structured by priority and research focus. This analysis results in the production of a set of **Thematic Research Summaries (TRS)**;
- **Policy analysis**, which pools research findings on a specific topic, with emphasis on the policy implications of results and pathways to future research. This analysis results in the compilation of Policy Brochures (PB).

The Thematic Research Summaries are designed to provide an overview of innovative research results relevant to the themes that have been identified as of particular interest to policy-makers and researchers. The classification structure adopted by the ERKC team comprises 45 themes divided into nine priority areas. Definitions of each theme can be found on the ERKC portal at

setis.ec.europa.eu/energy-research.

Table 1: Classification structure of R&D areas adopted by the ERKC

Priority area 1: Low-carbon heat and power suplly
Bioenergy / Geothermal / Ocean energy / Photovoltaics / Concetrated solar power / Wind / Hydropower / Advanced fossil fuel power generation / Fossil fuel with CCS / Nuclear fission / Nuclear fusion / Cogeneration / Heating and cooling from renewable sources
Priority area 2: Alternative fuels and energy sources for transport
Biofuels / Hydrogen and fuel cells / Other alternative transport fuels
Priority area 3: Smart cities and communities
Smart electricity grids / Behavioural aspects - SCC / Small scale electricity storage / Energy savings in buildings / ITS in energy / Smart district heating and cooling grids - demand / Energy savings in appliances / Building energy system integration
Priority area 4: Smart grids
Transnission / Distribution / Storage / Smart district heating and cooling grids - supply
Priority area 5: Energy efficiency in industry
Process efficiency / Ancillary equipment
Priority area 6: New knowledge and technologies
Basic research / Materials
Priority area 7: Energy innovation and market uptake
Techno-economic assessment / Life-cycle assessment Cost-benefit analysis / (Market-) decision support tools / Security-of-supply studies / Private investment assessment
Priority area 8: Socio-economic analysis
Public acceptability / User participation / Behavioural aspects
Priority area 9: Policy studies
Market uptake support / Modeling and scenarios / Enviromental impacts / International cooperation

The purpose of the Thematic Research Summaries is to identify and trace the development of technologies in the context of energy policy and exploitation.

The aim is to identify drivers of policy that will create a demand for 'products' that are likely to impact on policy in the coming years, especially technological acceleration, innovation, sustainable development, employment policy and international cooperation and social cohesion.

The TRS are intended for policy makers as well as any interested reader from other stakeholders and from the academic and research communities.

The present TRS deals with the theme Energy Efficiency in Buildings under Priority Area 3. It covers mainly energy savings in buildings, but also refers to building energy systems integration and, to some extent, ICT in energy.

Buildings are a key focus of EU energy policy and their improved performance will greatly contribute to the European climate and energy package. This publication aims to deliver a structured, though not necessarily comprehensive, overview of related research activities

carried out both at EU level and as part of nationally-funded and international programmes.

Chapter 2 includes a brief analysis of the scope of the theme, which is divided into eight main RD&D sub-themes (Table 2).

Table 2 Sub-themes for energy efficiency in buildings

Sub-theme	Description
1	Demonstrating energy efficiency in new and existing buildings
2	Nearly zero-energy buildings
3	New efficient solutions for energy generation, storage and conservation
4	Innovative materials and components for energy-efficient buildings
5	ICT technologies for energy-efficient buildings and public spaces
6	Energy efficiency improvement of buildings in urban areas
7	Tools and measures supporting energy efficiency policy
8	Environmental control and LCA approach in relation to energy efficiency of buildings

Chapter 3 provides an overview of the relevant EU policy context and of public funding allocated to RD&D in this sector. **Chapter 4** highlights trends in RD&D, summing up the results from a selection of meaningful research projects in the EU and beyond according to the eight sub-themes. References for selected projects are listed in Annex 2.

Chapter 5 lists some trends for future RD&D on energy efficiency in buildings, whilst **Chapter 6** mentions some policy implications. Finally, **Chapter 7** provides some key messages and lessons learned from the overview.

2 Scope of the theme

Buildings are the largest energy-consuming sector in the world, accounting for over one third of total global final energy consumption (40% in the EU) and an equally important share of carbon dioxide (CO2) emissions (35% in the EU).

In its Energy 2050 Roadmap the European Parliament acknowledged that the building sector must be 'a central element of the EU's long-term energy policy', and called for a reduction of 80% in the energy consumption of the existing building stock by 2050, compared to 2010 levels.

Buildings are complex products and both the building industry and the users of buildings have shown high inertia in the face of change. To achieve the EU's 2020 targets and the 2050 goals, innovation in the building industry and penetration of new technologies into the market are needed. Research and innovation must contribute accordingly.

Energy efficiency in buildings covers a wide range of themes. Construction is heterogeneous across different cultures and geographical areas (masonry, steel, steel and glass, reinforced concrete, wood, and brickwork). Energy peculiarities are likewise quite different, even if we consider only residential and non-residential uses of buildings. While the requirements for housing are somewhat standardised, tertiary buildings are conceived for a huge diversity of functional and performance characteristics and occupancy patterns: just think how different a hospital is from a school. Accordingly, socio-economic concerns and constraints determine diverse energy performance standards for new buildings, existing buildings, and historic or listed buildings.

The quality and energy efficiency performance of **building envelopes** affects the energy consumed by heating, ventilation and air conditioning (**HVAC**) equipment in buildings. At the same time, enhancing the performance of HVAC equipment and other energy-related services, through good maintenance, periodic upgrades and replacement, may improve a building's energy performance more effectively and at lower cost than is possible by retrofitting old or very inefficient building envelopes. The balance between advanced envelopes and advanced equipment, and the effect of this on energy efficiency, depends on the building type, product availability, cost, climate and local energy prices. Moreover, new materials, new energy supplies, **energy storage** and distribution technologies are changing the role of buildings. They are now moving from energy consumers to energy producers, even exporting energy to the grid, and promising much higher energy performance standards. New ICT enables **energy systems integration**, greater involvement from the

users of buildings and new opportunities for predicting, monitoring and controlling energy use.

Energy features in buildings interact with health and **indoor comfort**, safety, and functional aspects. The whole building process is energy-consuming, with an environmental impact, and needs a **life-cycle approach** from design to end of life.

In the context of the challenges mentioned above and the current policy context (see Chapter 3), the next chapter gives an overview of results and trends in RD&D on energy-efficient buildings.

2.1 Sub-themes

Current and ongoing research trends in energy-efficient buildings can be classified into the eight sub-themes described below, promoted under the 7th Framework Programme (FP7) and remaining partially relevant under the current Horizon 2020 (H2020) programme.

2.1.1 Demonstrating energy efficiency in new and existing buildings

The projects selected here aim to demonstrate the economic, social and technical feasibility of innovative technologies and systems relevant to buildings, and to bring them from the research prototype level to large-scale market exploitation in the short- or medium-term (i.e. by 2020).

The projects principally apply existing technologies to both new and existing buildings, in the envelope and in HVAC systems, and optimise their interaction. The building envelope performs many different functions, in both active and passive ways – the latter including insulation, reflective surfaces, orientation, and shading. The key challenge is therefore to optimise the design of the overall system to meet the needs of the occupants, minimising the requirement for heating and cooling equipment and maximising energy savings. Innovative solutions for design, construction, operation and management are analysed and put into practice, demonstrating the feasibility of getting these techniques into the market and the standards they can achieve (e.g. renovation factors from 4 to 10). Chapter 5 provides more details on the various techniques, but examples are:

- for the envelope: advanced insulation, high-performance windows, solar shading and protection;
- for HVAC: passive solar heating and active solar components, solar heating and cooling, day-lighting, integration of HVAC technologies (e.g. heat pumps).

2.1.2 Nearly zero-energy buildings

Projects in this area investigate new and integrated technologies and solutions for 'nearly zero-energy buildings' (NZEBs)[4] or better ('active' or 'plus energy') buildings, and also extend the goal to the neighbourhood level.

They aim to demonstrate, and make mainstream, cost-effective techniques and methods for achieving NZEBs in various climates. Some of the projects cover emerging technologies with high initial costs. More commonly, they investigate combinations of existing and new techniques, aiming at lower costs. Projects develop systematic approaches to monitoring and evaluation for scientific and comparative analysis and to facilitate the implementation of the recast Energy Performance of Buildings Directive ('EPBD recast' – see Chapter 3).

The RD&D includes analysis of market barriers and opportunities, for both the envelope and the building's technical systems.

RD&D technologies in this sub-theme include, for example: highly reflective envelope surfaces, small-scale solar cooling, integrated RES supply systems (geothermal, cold climate heat pumps, solar thermal, etc.), advanced and prefabricated envelopes, transmission controllable and intelligent windows, and smart buildings (also known as automated, integrated or intelligent buildings).

2.1.3 New efficient solutions for energy generation, storage and conservation

RD&D in this sub-theme addresses a combination of different technologies, such as optimised energy generation and storage technologies (using RES), to provide real-time accounts of energy demand and supply, and assistance with decision-making.

The core challenge is the creation of cost-effective techniques, tools and solutions to design, develop, install and assess the energy and environmental benefits of a new integrated concept of interconnected buildings, grids, and other networks at a district level.

These integrated solutions, for example, enable quick and cost-effective retrofits, improving efficiency by 30% and ensuring market acceptance, for instance by avoiding constraints incurred when upgrading envelopes. The main technologies and RD&D activities in this sub-theme are:

- adapting integrated seasonal thermal energy storage (STHS) systems and heat pumps (compact heat pump STES) to existing buildings;

[4] Article 2 of the EPBD in 2010 recast the definition of nearly zero-energy buildings as buildings that have a very high energy performance with nearly zero or very low energy use; this energy use is required to be covered to a very significant extent by energy from renewable sources, including from renewable energy produced on site and nearby.

- gas absorption heat pumps (GAHPs) for space heating and domestic hot water (DHW) in energy renovation; these allow a retrofit depth of over 40%, if using RES (air, ground, water);
- ICT to design and optimise district energy production and distribution, and to manage it in real time;
- cross-cutting issues: compatibility, interoperability between systems, standards for communication, innovation of business models and clustering activities.

2.1.4 Innovative materials and components for energy-efficient buildings

R&D in this sub-theme looks into more cost-effective, eco-compatible and durable products for the building envelope (walls, roofs, windows), exploiting the integration of nano-materials and nanotechnologies. Among these products are high-performance insulation systems, allowing thinner coatings or fillings, and other functionalities, including visual comfort, fire safety, maintenance, and indoor comfort. One RD&D challenge is to achieve better thermal and mechanical properties. Another is to gain wide commercial application, including a wider spread in the renovation of existing building envelopes. Targeted materials systems include aerogels, aerogel composites, nanofoams, and thin nanostructured insulators based on composite nanoparticles, which can be applied directly to a surface as a film, spray or paint. Photochromic, thermochromic, and electrochromic windows are also being studied. All of these new products also require a full product life cycle approach, including production, use, and disposal or recycling.

2.1.5 ICT technologies for energy-efficient buildings and public spaces

RD&D in ICT technologies is targeted at improving the energy efficiency of different types of buildings and public spaces by taking advantage of predictive modelling and control, and intelligent management systems. The main challenge is the knowledge-based and holistic optimisation of energy consumption – with a focus on cost-effectiveness and reliability – in ways that apply to a wide range of building types and climates within the EU. The intelligent energy management solutions are based on existing knowledge representation technologies, which are used in the context of smart buildings in combination with building automation systems. Energy consumption behaviour simulation with realistic visualisation assistance is included in this field.

2.1.6 Energy efficiency improvement of buildings in urban areas

In this area the RD&D focus is on groups of energy-efficient refurbished buildings and new 'energy autonomous' districts. The aim is to demonstrate that energy optimisation of districts and communities is more cost-effective than optimising each building individually. Contributions from key stakeholders work together to integrate different energy technologies in smart ways.

RD&D is being carried out on the use of local RESs, smart grids, cogeneration, district heating/cooling systems and energy management systems in larger settlements.

2.1.7 Tools and measures supporting energy efficiency policy

Projects in this area aim to improve the quality and quantity of energy efficiency interventions. They create the conditions to engage the public and private actors in identifying opportunities and barriers to better energy efficiency. They also study technical and administrative ways to overcome these barriers, which may be economic, regulatory, or financial. With this background the EU can put in place the interventions it needs to meet its energy efficiency targets and implement existing policies in the Member States, with their differing technical and legal situations.

Among these projects, mainly funded under the Intelligent Energy Europe programme, are the three Concerted Actions (CAs), which are joint initiatives of the Member States and the European Commission. Two of these CAs are closely linked to energy efficiency in buildings: the CA EPBD[5] and the CA EED. These share information and experience from national implementations of the Directives whose names they share – the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED), respectively – to influence the policy tools and standards developed by the Member States.

Other projects in this sub-theme have created repositories of best practices for energy-saving policies and developed tools to assist decision-making, taking into account new technologies and processes.

2.1.8 Environmental control and LCA approach in relation to energy efficiency of buildings

This sub-theme includes RD&D on monitoring and control of indoor environment quality (IEQ) and life cycle assessment (LCA) of buildings, considering the impact on the environment. In the first case, research addresses the simultaneous optimisation of IEQ and energy efficiency in buildings. In the second case, the aim is to provide benchmarks and guidance to construction practitioners, energy experts and other stakeholders on how to move towards meaningful comparisons of the 'whole life' energy efficiency of buildings, and to improve the ecological footprint of products, processes and services. Project results within this sub-theme can affect policies and strategies for products, waste and the sustainable use of natural resources, as well as construction products regulation (CPR).

[5] The Concerted Action EPBD, launched in 2005, involves those representatives of national ministries or their affiliated institutions, charged with preparing the technical, legal and administrative framework for the Energy Performance of Buildings Directive (2002/91/EC) in each country. The original Concerted Action EPBD came to a close in June 2007; a second phase ran until 2010. The current Concerted Action aims to transpose and implement the EPBD recast, Directive 2010/31/EU. It runs from 2011 to 2015.

3 Policy context

All over the world, energy efficiency is seen as the 'first fuel' – one that is competitive, cost-effective and widely available (IEA).

In the EU buildings are responsible for nearly 40% of our final energy consumption, about 35% of our CO2 emissions and more than 50% of all extracted materials. The construction sector is the leading industrial employer in Europe (accounting for 7.5% of industrial turnover and 18.1% of industrial jobs), with approximately 11 million workers directly employed.[6] EU householders spend on average 6.4% of their disposable income on home-related energy use; about two thirds of this is for heating and one third for other purposes.

The EU building sector has significant potential to save energy and cut CO2 emissions. This potential is being addressed by EU policies in order to mobilise the market and trigger benefits, including independence from energy imports, job creation, improved air quality and indoor comfort, and reduced fuel poverty.[7]

The 2011 European Energy Efficiency Plan[8] states: 'the greatest energy saving potential lies in buildings'. It spells out a series of energy efficiency policies and measures in this sector, covering the full energy chain, including energy generation and distribution. The Energy Efficiency Plan establishes the leading role of the public sector and the empowerment of final customers.

The 2011 EU Roadmap for Moving to a Competitive Low Carbon Economy in 2050[9] targets a reduction in the energy consumption of the existing building stock by 80% by 2050, compared to 2010 levels.

The 2011 Energy Roadmap 2050[10] considers buildings with high energy efficiencies key to a sustainable energy future, reduced energy demand, security of energy supply and increased competitiveness for Europe.

The 2011 Roadmap to a Resource Efficient Europe identifies buildings among the three key sectors responsible for 70–80% of all environmental impacts.

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[6] Source: European Federation of Building and Woodworkers (EFBWW)
[7] COM(2014) 520 final, Energy Efficiency and Its Contribution to Energy Security and the 2030 Framework for Climate and Energy Policy, July 2014.
[8] Energy Efficiency Plan 2011, COM(2011) 0109, http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1412274659458&uri=CELEX:52011DC0109
[9] COM(2011) 112 final
[10] COM(2011) 885 final

The Strategy for Competitive, Sustainable and Secure Energy (COM 2010 (639)) emphasises the need for more action in the field of buildings. It pays particular attention to renovation[11] and to a framework for financial support for energy efficiency in buildings.[12]

The most relevant policy instruments regulating this theme are three directives: the **Energy Performance of Buildings Directive** (EPBD) (2010/31/UE); the **Energy Efficiency Directive** (EED) (2012/27/UE) and its predecessors the CHP Directive (2004/8) and the Energy Services Directive (2006/32); and the **Renewable Energy Sources Directive** (RES Directive) (2009/28/EC). Together these establish a common framework for reducing energy consumption and increasing renewable energy use, addressing common topics, including energy certification, training, information campaigns, financial instruments, the exemplary role of the public sector, metering and monitoring.

The current EPBD[13] extends the scope and strengthens the aims of the original 2002 EPBD, which required Member States to improve building regulations, introduce energy certification schemes for buildings and inspect boilers and air conditioning systems. Leading issues are the move towards new and retrofitted nearly zero-energy buildings (NZEBs) by 2021 (2019 in the case of public buildings), and the application of a cost-optimal methodology to set minimum requirements for both the building envelope and the technical systems. Member States have reported a wide range of recent policies and measures to support NZEBs: financial support (16%), strengthened regulations (12.5%), awareness and education (12%), demonstration and pilot projects (10%), and, relevant to this TRS, R&D (4%).[14]

The EPBD stresses the cost-effectiveness and cost-optimality of energy efficiency measures and attributes an important role to the integration of renewables, remote heat and power generation. The cost-optimal methodology[15] introduces the concept of global lifetime costs: evaluating buildings' requirements beyond their initial investment costs will additionally take into account the operational, maintenance, disposal and energy-saving costs of buildings and building components.[16] The EPBD is also supported by elements of the EED (see below), mainly in the renovation of existing buildings.

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[11] COM 2010 (639) final.

[12] Report on Financial Support for Energy Efficiency in Buildings, COM(2013) 225 final, http://ec.europa.eu/energy/efficiency/buildings/doc/report_financing_ee_buildings_com_2013_225_en.pdf

[13] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, known as EPBD recast.

[14] National plans for nearly zero-energy buildings (http://ec.europa.eu/energy/efficiency/buildings/doc/ms_nzeb_national_plans.zip); Progress by MS towards Nearly Zero-Energy Buildings COM(2013) 483 final ; BPIE, Understanding (the very European concept of) Nearly Zero-Energy Buildings, April 2014 (http://www.eceee.org/policy-areas/Buildings/nearly-zero-energy-buildings/nZEB-maze-guide).

[15] EPBD recast was also supplemented by a 2012 Commission Delegated Regulation (EU) No 244/2012, supplementing Directive 2010/31/EU, establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements (http:/ec.europa.eu/energy/efficiency/studies/doc/2014_guidance_energy_renovation_buildings.pdf)

[16] Touching all sub-themes dealt with in this TRS.

The Directive on Energy Services[17], which includes energy end-use efficiency, requests Member States to set indicative energy saving targets by 2016 and to monitor their performance via periodic National Energy Efficiency Action Plans. As a follow-on, the EU adopted the EED as a cross-cutting measure to secure European energy efficiency targets for 2020 and beyond. The **EED**[18] aims to remove barriers that impede efficiency in the supply and use of energy. In the case of buildings, it requires each Member State to define a long-term strategy beyond 2020 for mobilising investment in the renovation of all public and private buildings (article 4). As buildings owned by public bodies account for a considerable share of Europe's existing stock, the public sector should lead by example. The EED therefore requires the renovation of 3% a year of buildings owned and occupied by central government, starting from 2014 (article 5), and the inclusion of energy efficiency considerations in public procurement. Some national building renovation strategies are already in place: Germany, for example, is aiming for an 80% cut in the energy consumption of its entire building stock by 2050. A shift to a deep renovation ratio of 2%, from 1% currently, is commonly assumed to be required to achieve the targets.

Other issues covered by the EED are metering and billing, demand response and grid issues, energy auditing, consumer information programmes, professional training and certification, high-efficiency CHP, and heating/cooling.[19]

The **RES Directive** establishes a common framework for the use of renewable energy, including electricity and the heating and cooling of buildings. It requires Member States to submit National Renewable Energy Action Plans (NREAPs) describing concrete measures.

Looking more specifically at EU product policy, the **Construction Products Regulation** (CPR) (No 305/2011) lays the basis for more energy-efficient building projects that use as little energy as possible during construction and dismantling. Energy issues are covered indirectly under the heading of sustainable use of natural resources. This provides a rationale for research on sustainable materials and products; topics include the durability of products, the reuse or recycling of materials at the end of the life of the product or the building, and the use of eco-compatible raw and secondary materials.[20]

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[17] Directive on Energy Services (2006/32/EU).
[18] Directive on Energy Efficiency (2012/27/EU).
[19] Research in sub-themes 1-3-5-6-7-8 may affect the implementation of the EED.
[20] Key reference standardisation linked to new RD&D on social, economic and environmental issues in this area is included in CEN/TC 350 Sustainability of Construction Works http://standards.cen.eu/dyn/www/f?p=204:32:0::::FSP_ORG_ID:481830&cs=181BD0E0E925FA84EC4B8BCCC284577F8
[21] Directive of the European Parliament and of Council establishing a framework for the setting of ecodesign requirements for energy-related products (2009/125/EC).
[22] Directive of the European Parliament and of the Council on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products (2010/30/EU).

As strategic market instruments the **Eco-design Directive**[21] and the **Energy Labelling of Domestic Appliances Directive**[22] provide cues for new standards and improved energy use in buildings:

- The Eco-design Directive provides rules to improve the performance of energy-related products and aims to facilitate their trade within the EU as a result. Beyond appliances and equipment that use energy directly (boilers, computers, televisions, etc.), windows and insulation materials are key energy-related products that will soon be subject to this Directive.
- The Energy Labelling of Domestic Appliances Directive establishes a framework to provide consumers with useful information allowing them to choose and use more energy-efficient products.

Energy recovery from construction and demolition waste is covered by the Waste Directive (2008/98/EC). The reduction of energy inherent in goods, works and services purchased by public authorities falls under the latest revision of the Public Procurement Directives (2014/24/EU).[23]

RD&D on energy efficiency in buildings is promoted by the ongoing **Horizon 2020** programme (2014–20), a major instrument in leveraging the delivery of innovative products and systems, as well as policies and business models for energy efficiency. Linked to Horizon 2020 are the ongoing **Cohesion Policy Funds**[24] and **COSME** joint initiatives; these promote research, innovation, procurement, certification and the creation of inter-regional clusters to speed up the uptake of new knowledge and technologies at EU and regional levels.

Existing initiatives like the Public Private Partnership on Energy-efficient Buildings (EeB PPP), Culture Heritage, the Smart Cities platforms, reFINE (Research for Future Infrastructure Networks in Europe) and the Covenant of Mayors could all provide bases on which to develop energy efficiency partnerships. A number of municipalities and other public bodies in the Member States have already experienced integrated approaches[25] to energy saving and energy supply that directly involve citizens and urban stakeholders (see also the Smart Cities TRS).

Finally, the **2030 Policy Framework**[26] is an important intermediate milestone in delivering the EU's strategy for 2050. The Policy Framework

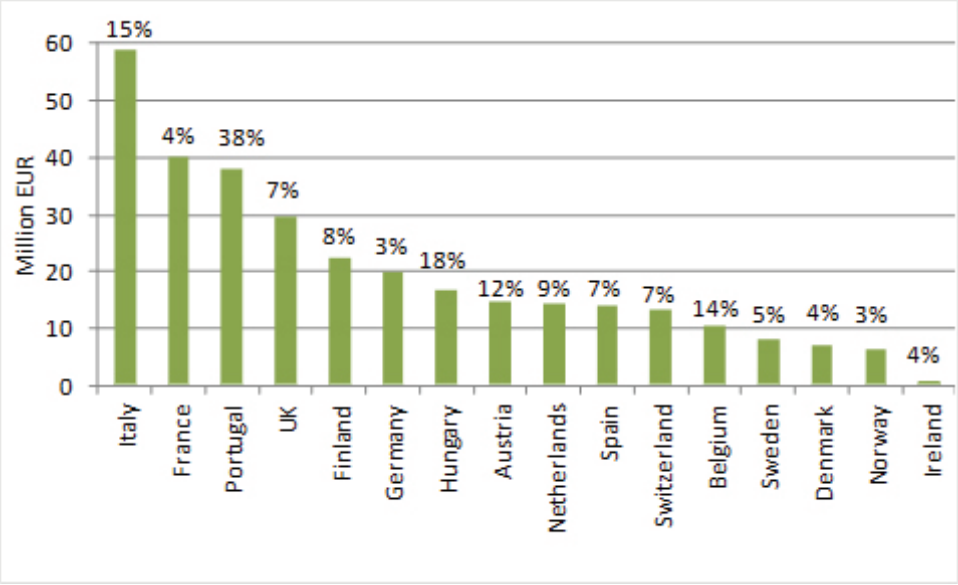
[21] Directive of the European Parliament and of Council establishing a framework for the setting of ecodesign requirements for energy-related products (2009/125/EC).
[22] Directive of the European Parliament and of the Council on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products (2010/30/EU).
[23] http://ec.europa.eu/internal_market/publicprocurement/modernising_rules/reform_proposals/index_en.htm, Directive 2014/24/EU replacing directive 2004/18/EC Directive 2014/25/EU replacing directive 2004/17/EC.
[24] Technical Guidance 'Financing the energy renovation of buildings with Cohesion Policy Funding, DG ENER 2014.
[25] CONCERTO programme http://concerto.eu/concerto/policies.html and the LEAD market initiative http://ec.europa.eu/enterprise/sectors/construction/studies/national-building-regulations_en.htm
[26] A Policy Framework for Climate and Energy in the Period From 2020 to 2030, COM(2014) 15 final

mentions the construction sector for its business opportunities[27]. Although the EU's indicative target is 30% energy savings by 2030, clear objectives for energy efficiency have not been fixed. Several key stakeholders and some Member States are asking for more ambitious and binding targets.

In the last decade Europe has witnessed an increase in **public R&D expenditure** on energy efficiency by the Member States. The amounts spent have started from very different levels in the various economies and reflect general increases in total public funding for energy research.

The International Energy Agency RD&D Statistics Database[28] indicates that total public expenditure for RD&D on energy efficiency for residential and commercial buildings and equipment in Europe was about EUR 315 million in 2011. The country with the highest expenditure in absolute terms was Italy (EUR 59 million), followed by France (EUR 40.2 million) and Portugal (EUR 38.1 million). Looking at spending on energy efficiency RD&D in buildings compared to energy research as a whole, Portugal had the highest share, at 38%.

Figure 1: Expenditure on RD&D related to energy efficiency in buildings and equipment in the EU Member States, Switzerland and Norway, 2011. Shown as total spending (EUR million) and as a percentage of total national RD&D expenditure in the energy sector (2012 prices and exchange rates)



Source: IEA RD&D Statistics Database

[27] COM(2014) 520 final, see note 7.
[28] Data refer to IEA member countries, excluding the Czech Republic, Greece, Luxembourg, Poland, and Slovakia, for which 2011 data was not available.

4 Research findings

This chapter synthesises major RD&D results from selected recent EU, national and international projects, listed according to the eight sub-themes introduced above. The main sources of information for chapter are FP7 (the CORDIS database[29] and project websites), project websites from the CIP IEE programme, and IEA ETN and IA reports and web information.

Most of the selected projects in FP7 were funded under the PPP EeB.[30] The EeB roadmap provided a common framework for multidisciplinary work, assuring high levels of commitment from different stakeholders. For 2010 the proportions were: higher education 15%, private for profit 53%, research organisations 24%, SMEs 30%.

These projects were required in order to provide:

- more industrial investment in R&D;
- involvement of companies across a range of countries, including small countries (26 in the 2010 call);
- market penetration of new technologies;
- a knowledge base for SMEs.

Section 4.2 includes a small analysis of national programmes. This does not necessarily include all the relevant projects developed under the EUREKA and COST programmes.

[29] E2B, ECTP, EeB PPP Projects –7Review http://ec.europa.eu/research/industrial_technologies/pdf/eeb-ppp-project-review-2010-2011_en.pdf

[30] The Public-Private Partnership (PPP) on Energy-efficient Buildings launched in December 2008 under the European Economic Recovery Plan. It attracted a large amount of industrial participation and helped to innovate in the building sector. More info on www.e2b-ei.eu.

4.1 EU projects

Table 3: List of EU projects and results by sub-theme

Sub-theme 1: Demonstrating energy efficiency in new and existing buildings	
Project	Main results
E2ReBuild Industrialised energy efficient retrofitting of residential buildings in cold climates	• Renovation to Factor 6 overall energy reduction • Energy use reduced to 30–50 kWh/(m² year) (heating, ventilation and hot water), meeting national EPBD 2010 limits for new buildings • Space heating energy use reduced by about 75% • Efficient industrialised renovation replicable models (e.g. by prefabricated timber elements with U = 0.13 W/m2K) • Methodology/technical applicability to 60% of EU building stock
School of the Future Towards zero emission with high performance indoor environment	• 100% carbon-free school buildings with improved IAQ and limited additional costs (around EUR 150 /m²) • Solution sets for zero emission/energy surplus schools • Best retrofit technologies (technology screening), encompassing IEQ, construction elements, reduction of heat losses from the building envelope, optimal handling of gains, heating, ventilation and lighting systems, energy supply/ generation, design, construction, commissioning and monitoring • Simple energy performance calculation tool
3ENCULT Efficient energy for cultural heritage	• Renovation to Factor 4–10 overall energy reduction • Energy efficiency solutions: criteria, recommendations for local government, multi-disciplinary planning process (ICT plugs into BIM software), passive house planning package • Contribution to standard CEN TC 346 WG8 (historic buildings)
BRITA in PuBs Bringing retrofit innovation to application in public buildings	• Renovation to Factor 2.2 primary energy reduction • User satisfaction doubled • Public buildings retrofit guidelines • Higher awareness in demonstration countries • Definition of eco-buildings in FP7 • Socio-economic analysis of barriers and needs • Financial strategies for low-energy public retrofits in Europe

Sub-theme 2: Nearly zero-energy buildings	
Project	Main results
DIRECTION Demonstration at European level of innovative and replicable effective solutions for very low energy new buildings	• Primary energy consumption below 60 kWh/(m^2 year) • Over 50% energy reduction using cost-effective measures • Over 60% CO2 emissions reduction • Modelling, simulation and building monitoring techniques (ICT) • Stakeholder awareness • Contribution to standards and regulations
NEXT-Buildings next zero energy buildings at lowest cost by using competitive sustainable technology	• Demonstrations of ICT-based inhabitant energy feedback systems • System for neighbourhood load control • Building-integrated PV panels and transmission controllable windows (dual function insulation/PV building elements, ensuring simultaneously optimal insulation and power generation, easy handling, aesthetics, and cost-effectiveness) • Development of an intelligent window to steer daylight • Demand-controlled ventilation with user interface • Extensive dissemination programme (Results are only partially available at the moment)
IEE ENTRANZE Policies to enforce the transition to nearly zero energy buildings in the EU27	• Solutions to remove market barriers to NZEBs • Actively supporting policymaking by providing the required data, analysis and guidelines • Facilitating a rapid and deep penetration of NZEBs into existing national building stocks (linked to EPBD)

Sub-theme 3: New efficient solutions for energy generation, storage and conservation	
Project	Main results
EINSTEIN Effective integration of seasonal thermal energy storage systems in existing buildings	• Primary energy savings of up to 70%, compared to conventional existing thermal systems, obtained through integration of seasonal thermal energy storage (STES) and heat pumps (HPs) • Development of high-efficiency, cost-effective and compact heat pump STES • Decision support tool for STES selection, design and evaluation
RESILIENT Coupling renewable, storage and icts for low carbon intelligent energy management at district level	• Combination of different technologies, including smart ICT components optimising energy generation and storage (combining the microgrid and energy hub concepts) • New components and systems enabling cost-effective, energy-efficient, renewable energy supply through co- and poly-generation, solar energy storage systems (electrical and thermal), electricity, heating and cooling networks • District energy management system (DEMS), based on ICT for providing real time accounts of energy demand and supply

HEAT4U Gas absorption heat pump solution for existing residential building	• Space heating and domestic hot water (DHW) solutions in energy renovation of existing buildings through cost-effective gas absorption heat pump (GAHP) technology, using existing gas grid and without upgrading electrical generation, transmission or distribution • Products for residential applications with 10–25 kWth nominal output and 150–170% global efficiency (air source, air temperature 2 °C, producing hot water at 50 °C, 100% load) • Several GAHP demonstrations: - 10 renovated supermarkets in northern Italy cut CO2 emissions by up to 53.6 tonnes/year compared to conventional boilers - School with geothermal GAHP consumes only 24 kWh/(m^2 year) (previously 140 kWh/(m^2 year), saving up to 80% on operating costs - Residential: household compensating CO2 emissions produced by their car

Sub-theme 4: Innovative materials and components for energy-efficient buildings	
Project	Main results
NANOPCM New advanced insulation phase change materials (PCM) (new buildings)	• Development of enhanced lightweight materials: insulation foams based on polyurethane, improved by adding phase change material (PCM) microcapsules, store and release energy depending on the weather • LCA improved eco-compatibility
COOL-Coverings development of a novel and cost-effective range of nanotech improved coatings	• New cost-effective nanotechnology improved coatings • Infrared-reflecting nanomaterials (NIR) used for paint, membranes and tiles for outdoor application, based on inorganic nanostructured materials • Applicable to new and existing buildings • Reduced heat transfer through the envelope via NIR
NANOINSULATE Development of nanotechnology-based insulation systems	• New vacuum insulation panels (VIPs) incorporating nanotechnologies (nanofoam, aerogel) and high-barrier films • Durable, robust, cost-effective, opaque and transparent VIPs with a lifetime of over 50 years, suitable for a variety of building applications • Manufacturing costs less than half current costs
AEROCOINS Aerogel-based composite/hybrid nanomaterials for cost-effective super insulation systems in buildings	• New super-insulating materials for the envelope (silica-based aerogel with super-insulating components) • Improved mechanical performance • Improved cost-effectiveness • 30% overall energy saving and 25% less CO2 emissions

Sub-theme 5: ICT technologies for energy-efficient buildings and public spaces	
Project	Main results
KnoholEM Knowledge-based energy management for public buildings through holistic information modelling and 3D visualisation	• Intelligent energy management solution for energy-efficient buildings and public spaces • Average 30% energy savings, depending on the demonstration case • Main deliverables: - Analysis of building use - Data mining algorithm - Protocols and standards in building-grid communication - Web-based smart building simulator, visual monitoring tool - Evaluation procedure for energy savings and investment amortisation
Odysseus Open dynamic system for saving energy in urban spaces	• Open dynamic system enabling 'holistic energy management' in urban areas (Rome and Manchester) • Based on dynamics of energy supply, demand and storage • Long-term decision support: - tactical or even strategic adaptations (adding or changing nodes) - Real-time optimisation
ICT4E2B Forum	• Creation of a dynamic community representing ICT, construction and energy players • Validated roadmap dedicated to ICT applications for energy efficiency in buildings (useful for H2020 developments)

Sub-theme 6: Energy efficiency improvement of buildings in urban areas	
Project	Main results
CONCERTO	• Platform on best practices and smart technologies to reduce the carbon impact of buildings • Best practices (58 cities and communities) including: - innovative EE and RES measures and technologies for sustainable buildings and districts - energy transparency for citizens - demonstrated 50% cut in CO2 emissions at acceptable cost
E-Hub Energy-hub for residential and commercial districts and transport	• Smart grid type of energy infrastructure, based on matching supply and demand for heat, cooling and electricity • Smart energy control and energy management system to transfer energy from the most readily available local sources to the destinations where it is required • Development of compact heat storage technologies based on thermochemical materials

Sub-theme 7: Tools and measures supporting energy efficiency policy	
Project	Main results
PROFICIENT SME network business model for collective self-organised processes in the construction and retrofit of energy efficient residential districts	• New processes and business models • Regulatory and ICT tools • Business models for SME networks
MURE II database	The MURE II database provides a general overview of ongoing energy efficiency policy measures in EU Member States, plus Norway. Lists around 460 targeted energy end-use instruments and measures in the residential sector, and around 390 in the non-residential sector, mainly on space heating and hot water. The most active country by number of ongoing measures and instruments in both sectors is Spain (almost 17% of the total), followed by Estonia (8.5%) and Italy (7%). In the period 2000–11, Slovakia achieved the highest energy savings per dwelling, followed by Luxembourg, the UK, Belgium and Romania. Luxembourg, Finland, Norway and Austria show the highest specific energy consumption, normalised for climate.
Various projects under the CIP-IEE Intelligent Energy Europe Programme, e.g. **CA EPBD** Concerted Action EC-EU MS **Tabula** Typology Approach for Building Stock Energy Assessment	**CA EPBD** information and experience shared from national implementation of EPBD recast (2010/31/EU) (2011–15)
	Tabula • Residential building typologies defined and exemplified for 13 European countries (according to their size, age and other parameters) • Web tool for online calculation of the example buildings, energy-related features and possible energy savings through refurbishment • Scenario analysis: building stock models which enable modelling of energy consumption by the national building stock, and energy saving potential

Sub-theme 8: Environmental control and LCA approach in relation to energy efficiency of buildings	
Project	Main results
CETIEB Cost-effective tools for better indoor environment in retrofitted energy efficient buildings	• Indoor environment quality (IEQ) monitoring systems (wireless and/or partly wired) to measure comfort and health parameters. Quick check of indoor air quality by users. • IEQ control systems based on photocatalytic materials or PCMs • IEQ modelling while optimising energy efficiency
EeBGuide Operational guidance for life cycle assessment studies of the energy efficient buildings initiative	• Guidance helping private and public LCA practitioners to quantify environmental impacts in a consistent manner • Applicable to LCA for whole buildings (both existing and new), building products, technological solutions, such as HVAC systems • Info hub providing operational guidance
HESMOS ICT platform for holistic energy efficiency simulation and lifecycle management	• Main deliverable: integrated virtual energy laboratory (IVEL) • Industry-driven holistic approach for sustainable optimisation of energy performance and CO2 emissions reduction • Integrated existing intelligent building/facilities data, allowing life cycle simulation of design, refurbishment and retrofit phases • Information interoperability achieved by enhancing BIM with energy and emissions features (new sharable eeBIM)

4.2 Other projects funded at international and national level

The results of National R&D programmes are often difficult to access or are available only in native languages. Two extensive programmes covering RD&D on most of the selected sub-themes are summarised below.

Table 4: List of national projects

Project	Main results
Grenelle 2 (France)	Grenelle 2 is the law establishing France's national commitment to the environment in the building sector. It supports technological advances and promotes efficient use of urban land resources and energy. Starting in 2020, new buildings must be energy positive. Starting in 2013, old buildings must be renovated at a rate of 400 000 per year. Under this umbrella programme research is carried out on sustainable buildings (new and existing), IEQ, innovative materials, etc., with a contribution from CSTB (www.cstb.fr). Example projects: PREBAT2 (www.prebat.net) EcoQuartiers (www.territoires.gouv.fr/les-ecoquartiers)
House of Tomorrow Plus programme (Haus der Zukunft Plus) (Austria)	House of Tomorrow Plus was a programme financed by the Austrian Ministry for Transport, Innovation and Technology. It aimed to use fundamental research, cooperation in technology development and accompanying measures, and demonstration projects to commercialise energy-related innovations in the building sector. Topics included: key technologies for future buildings; strategies, education and networking; demonstration buildings; and industrial transformation of innovative technologies. The programme started in 2010 and finished in 2013. Funded projects dealt with: – low-energy solar; – passive building; – ecological materials and systems.

International projects mentioned below are selected from the ongoing international research programmes known as Implementing Agreements (IAs) within the IEA Energy Technology Network (ETN). IEA IAs are an important part of the Agency's programme, involving RD&D collaboration in new energy technologies to reduce excessive reliance on imported oil, increase long-term energy security and reduce greenhouse gas emissions. The main building-related IA programmes are:

- EBC – Energy in Buildings and Communities;
- ECES – Energy Conservation through Energy Storage;
- DHC – District Heating and Cooling;
- HPP – Heat Pumping Technologies;

- 4E – Efficient Electrical End-Use Equipment;
- DSM – Demand Side Management (Electricity);
- SHC – Solar Heating and Cooling.

Most of the projects (named annexes or tasks) in these programmes bridge research and innovation with energy policy and socio-economic challenges.

IEA-IAs include collaborations (or plan to do so) in the following RD&D areas:

- System integration applied to 'deep renovation';
- District and community research (society, ICT, environment);
- Cost-effectiveness of products and techniques, to reduce costs and increase reliability;
- Energy storage, with a growing role in RES integration, increased energy efficiency and interoperability between systems.

Table 5: International projects in the IEA IAs, categorised under the eight sub-themes

1 Demonstrating energy efficiency in new and existing buildings	**EBC Annex 50 – Prefabricated Systems for Low Energy Renovation of Residential Buildings (ended in 2011)** Roof systems with integrated HVAC, hot water and solar systems; highly insulated envelopes with integrated new distribution systems for heating, cooling and ventilation. - Building Typology and Morphology of Swiss and French Multi-Family Homes - Retrofit Simulation Report on energy efficiency of renovated buildings **SHC Task 47 – Renovation of Non-Residential Buildings Towards Sustainable Standards (ended in 2014)** Projects show a 50-90% reduction in heat consumption and a 50-70% reduction in overall energy demand. One case (Norway) achieved a plus energy standard combined with the highest BREEAM score. Simulation, Barriers and opportunities of decision-making processes **SHC task 50: Advanced Lighting Solutions for Retrofitting Buildings** Energy audits and tools, case studies assessment. List of Advanced Lighting Solutions for Retrofitting Buildings

2 Nearly zero-energy buildings	**EBC Annex 52 – SHC Task 42: Towards Net Zero Energy Solar Buildings** Development of an energy evaluation methodology to predict HVAC&R system energy demand for office buildings. Case studies, with a supporting sourcebook, guidelines and tools. A review of case studies on 30 Net ZEBs is provided.
3 New efficient solutions for energy generation, storage and conservation	**ECES Annex 23: – Applying Energy Storage in Ultra-low Energy Buildings** Evaluation of energy storage in energy-efficient buildings: concept development and demonstration projects. Best practices for architects and engineers. Application of PCM (Phase changing materials).
6 Energy efficiency improvement of buildings in urban areas	**EBC Annex 51 – Energy Efficient Communities – Case Studies and Strategic Guidance for Urban Decision Makers** Understanding system synergies, implementing optimised energy strategies. Integrated approach to develop municipal energy master plans. Supplied state of the art of planning methods (tools and models). **DHC (Task S1) – Low Temperature District Heating for Future Energy Systems** Fundamental links between low-temperature systems, integration of renewables, thermal storage and heat demands of future buildings, implying the need for research on methods and planning tools, technologies, communities and interfaces.
7 Tools and measures supporting energy efficiency policy	**EBC Annex 56 – Cost- Effective Energy and CO2 Optimisation in Building Renovation** Targets for energy performance and carbon emissions in building renovation; combinations of energy efficiency and low-carbon measures; tools to support decision-makers.
8 Environmental control and LCA approach in relation to energy efficiency of buildings	**EBC Annex 55 – Reliability of Energy-Efficient Building Retrofitting – Probability Assessment of Performance and Cost** Prediction of energy use, LCC and functional performance, real-life case studies, guidelines for practitioners. **EBC Annex 57 – Evaluation of Embodied Energy and Carbon Dioxide Emissions for Building Construction** Methods for evaluating embodied energy and CO2 emissions. Guidelines to help practitioners find better design and construction solutions.

5 R&D developments

At European level, the Energy Efficient Buildings Association (E2BA) publishes a Multi-Annual Roadmap for the Contractual PPP on Energy Efficient Buildings Under Horizon 2020 (c-PPP EeB), where 'PPP' refers to public-private partnerships. The Roadmap sets out a vision of a high-tech building industry, and looking forward to 2030 it proposes research and innovation priorities agreed amongst the wide community of stakeholders across Europe.[31]

The priorities for the building industry in this Roadmap are:

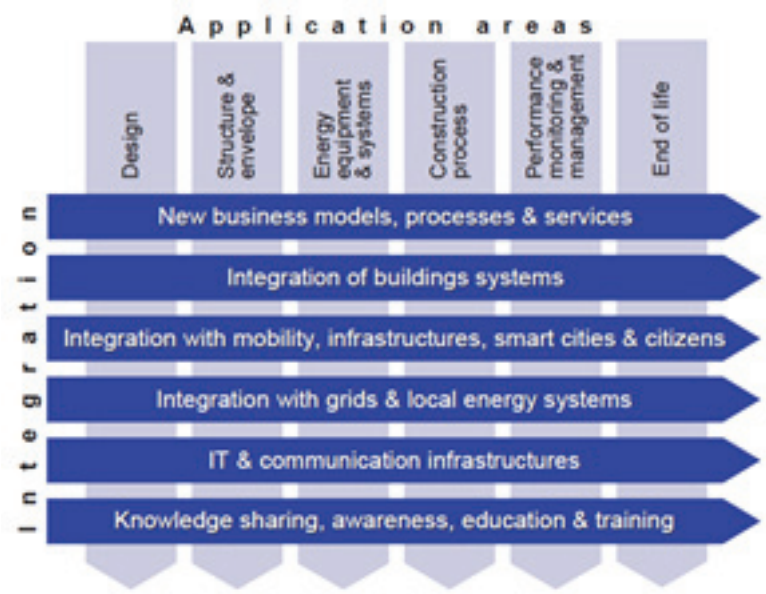
- user-centric and affordable buildings, both new and refurbished, and districts;
- construction quality standards for the life cycle of buildings;
- valuing environmental, aesthetic, historic, safety, accessibility and comfort aspects;
- long-term guaranteed contracts for energy performance.

Specific R&D objectives are:

- innovative construction techniques, multi-target design and prefabrication methods for the building envelope;
- solutions for building retrofits that integrate innovative energy equipment and storage;
- interactive and sustainable buildings with zero or positive energy balances, and extension of this concept to the district level;
- performance monitoring tools to ensure energy efficiency and comfort during the service life (including durable components);
- an enabling role for ICT along the value chain, from design to end of life.

[31] European Commission, E2BA, 2013
www.ectp.org/cws/params/ectp/download_files/36D2981v1_Eeb_cPPP_Roadmap_under.pdf

Table 6: ICT's enabling role along the whole value chain (from PPP EeB Roadmap 2014–20)



Under Horizon 2020, the pillar Societal Challenge within the work programme Secure, Clean and Efficient Energy supports innovation through R&D on energy-efficient technologies (EeB-PPP), research and innovation on products (RIA), and market uptake (MU). The Energy Efficiency 2014–15 work programme includes the following building-related topics:

H2020 Societal Challenges – Energy Efficiency – Buildings and Consumers

EE1 (PPP)	Manufacturing of prefabricated modules for renovation of buildings
EE2 (MU)	Buildings design for new highly energy performing buildings
EE3 (PPP)	Energy strategies and solutions for deep renovation of historic buildings
EE4 (MU)	Construction skills
EE5 (MU)	Increasing energy performance of existing buildings through process and organisation innovations and creating a market for deep renovation
EE6	Demand response in blocks of buildings
EE7 (MU)	Enhancing the capacity of public authorities to plan and implement sustainable energy policies and measures
EE8 (MU)	Public procurement of innovative sustainable energy solutions
EE9 (MU)	Empowering stakeholders to assist public authorities in the definition and implementation of sustainable energy policies and measures
EE10 (MU)	Consumer engagement for sustainable energy
EE11 (RIA)	New ICT-based solutions for energy efficiency
EE12 (RIA)	Socioeconomic research on energy efficiency

H2020 Societal Challenges – Energy efficiency – Heating and Cooling

EE13 (RIA)	Technology for district heating and cooling
EE14 (MU)	Removing market barriers to uptake of efficient heating and cooling

The H2020 pillar Leadership in Enabling and Industrial Technologies (LEIT), Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing promotes the following topics:

H2020 LEIT – Energy-efficient Buildings (EeB

EeB 1	Materials for building envelope
EeB 2	Adaptable envelopes integrated in building refurbishment projects
EeB 3	Development of new self-inspection techniques and quality check measures for efficient construction processes
EeB 5	Innovative design tools for refurbishing of buildings at district level
EeB 6	Integrated solutions of thermal energy storage for building applications
EeB 8	Integrated approach to retrofitting of residential buildings
EeB 7	New tools and methodologies to reduce the gap between predicted and actual energy performances at the level of buildings and blocks of buildings

At **national level** many R&D strategies for energy and buildings are moving from sustainable buildings and neighbourhoods towards sustainable cities: this is the case in France[32], Austria and Italy. The challenge for R&D is to integrate building priorities and benefits into smart cities. Building R&D (such as on health and comfort, energy saving in new and existing buildings and demand response) must be able to promote interactions and create interdisciplinarity at different levels, and within different contexts (existing buildings, public spaces, infrastructures and services) and energy systems.

At **international level**, RD&D within IEA building-related programmes (IAs) is also strengthening its focus on **ICT, behaviour and system integration**[33]. This is a crucial aspect of RD&D for smart cities, bringing together stakeholders, who can help to identify needs, overcome challenges and take advantage of opportunities.

A growing role for **storage** technologies can be observed. This has produced RD&D on decentralised energy storage technologies for integrating fluctuating renewable energy sources into future energy systems[34], and energy storage solutions to address the significant time mismatches between energy demand and energy production in NZEBs.[35]

An opportunity for collaboration around the community dimension will follow publication of the 2016 IEA Energy Technology Perspective (ETP) on Urban Energy.

[32] CSTB report, Recherche – Feuilles de Route Pour l'Horizon 2020 www.cstb.fr/fileadmin/documents/telechargements/2012-Feuilles_de_route.pdf

[33] E.g. activities in IA DSM – Task 17 *Integration of Demand Side Management, Distributed Generation, Renewable Energy Sources and Energy Storages and DSM* – Task 24 *Energy and Behaviour, and new IA-EBC Annex 66 – Occupant Behaviour Simulation.*

[34] ECES Annex 28 – *Integration of Renewable Energies by Distributed Energy Storage (DES) Systems*.

[35] ECES Annex 31 – *Integration of Energy Storage with NZEB.*

6 Policy implications

Exploitation of the RD&D results mentioned above may yield:

- Data classifying building stocks according to their thermal quality, use, size, age, efficiency of heating and cooling systems, and types of users and investors. This in turn will aid the creation of policy scenarios for implementing the main Directives (EED, EPBD, RED, Ecodesign Directive).
- Cost-effective and cost-optimal technology configurations (both minor renovation measures and deep renovation in line with the EPBD) that could be associated with labels or performance certificates.
- Recommendations for local, regional and national policymakers that address the whole range of policy instruments, including building standards, mandatory codes,[36] obligations, grants, procurement, communication campaigns and voluntary agreements. These instruments can help to stimulate private-sector involvement, as for instance in the LEED and BREEAM certification schemes[37].

Solutions for cost-effective reduction of waste from construction products, use of natural resources and increased material re-use, building renovation and NZEBs, contribute to the **sustainable competitiveness of the construction sector and its enterprises**.[38]

The **2030 policy framework**[39] identifies energy efficiency measures, electrification and thermal energy supply from RES (e.g. CHP from waste) as technologies to be promoted in the renovation of both residential and non-residential buildings.

[36] Policy Pathway for Modernising Building Energy Codes to Secure our Global Energy Future (IEA, 2013a), and in Transitioning to Sustainable Buildings: Strategies and Opportunities to 2050 (IEA, 2013).
[37] See 'Transition to Sustainable Buildings: Strategies and Opportunities to 2050' for more information (IEA, 2013).
[38] COM(2012) 433 final
[39] A Policy Framework for Climate and Energy in the Period From 2020 to 2030, COM(2014) 15 final

7 Conclusions and recommendations

When comparing projects results, it is evident how demonstration cases (in sub-themes 1, 2, 3, 5 and 6) are able to meet increasingly stringent performance benchmarks both for new and renovated buildings. For example, a comparison of case studies from FP6 and FP7 shows an increase in the renovation factor from 2 to 6 or more.

Technological RD&D on energy efficiency in buildings reflects our changing approach to producing and consuming energy. Advances have been made in new materials and components, deployment of new technologies, such as energy storage, assessment and planning methods, and prediction, monitoring and management of energy performance through ICT.

Energy system integration at district scale and interaction between the various energy networks have begun for both building retrofits and new construction; retrofitting strategies were recognised as the more critical in terms of their technical aspects. Projects in this area have proved the viability of sets of innovative technologies and measures, with substantial contributions from local RES, smart grids, renewables-based cogeneration, district heating/cooling and energy management systems. Projects have addressed both local specifics and possible transferability.

Due to the complexity of the building process – characterised by fragmentation and a multitude of stakeholders, from initiation and commitment to operation and maintenance – 'system efficiency' still remains a priority for RD&D. In this regard we see some advances in the integrated design approach, in terms of proper assessment and evaluation tools that also take into account energy affordability and transparency to citizens.

The analysis undertaken for this TRS shows that the eight selected sub-themes are still relevant to future RD&D in the short term, as the H2020 topics for the period 2014–15 confirm. The upcoming **Integrated Roadmap**, which consolidates the **SET-Plan**[40] and the outcomes of the ongoing process of R&D planning through the EeB PPP, will drive the research and technology agenda for **H2020**.

[40] Scoping paper in the communications on energy technologies and innovation, June 2013 (www.gridplus.eu/Documents/EEGI%2010/Scoping%20Paper-%20Integrated%20roadmap%20130613%20.pdf);
Draft outline for the integrated roadmap, October 2013 (https://www.innovateuk.org/documents/3133919/9877878/Strategic+Energy+Technology+Plan+-+draft+Integrated+Roadmap+for+comment/2b05b0f5-5890-40f7-99fe-20bdcb228fcf, MS Word document)

In line with energy efficiency's change in focus 'from building to city',[41] future R&D is likely to address issues such as: the relationship between the built environment, transport and mobility; transforming cities into energy plant; self-sustaining cities; ICT and digital society opportunities for the construction sector; risk management and affordability; the inclusive society; cultural heritage; and resource efficiency.

The main highlights for the policy context are:

1. Climate and energy targets should take on board future technological developments and learning curves. Currently available technologies already offer wide potential for energy savings of 60–75% and there is already a target to cut energy consumption by 80% by 2050.
2. Technology-oriented activities should be always combined with socio-economic research into market-based and demand-side instruments. The latter include training, public procurement, standardisation and insurance.
3. Innovative approaches, involving environmental, economic, and social (behavioural and governance) aspects at wider levels (district and city-wide), are needed.
4. Efficient products and processes help to build industrial capacity in Europe as well as better skills of all involved actors in the building process.
5. Enhancing the competitiveness of SMEs, including their use of ICT, remains a priority.
6. EU Cohesion Policy can support research and innovation under national programmes that comply with regional Smart Specialisation Strategies.[42]

Further EU policy efforts in this field are recommended[43] to ensure:

- effective transposition, implementation and enforcement of existing legislation in the building sector in the decades to 2050;
- increased focus on standards for products and techniques;
- open-source access to buildings performance data and innovation processes;
- increased capture and articulation of the multiple benefits of energy efficiency investments, for the benefit of decision-makers.

[41] ECTP-E2BA CONFERENCE, Construction and Built Environment Future Horizons Brussels, 17–19 June 2014.
[42] http://s3platform.jrc.ec.europa.eu/home?CFID=0dc46b15-0b05-4df5-b753-bc8fbae83225&CFTOKEN=0
[43] E.g. Energy Efficiency Financial Institutions Group (EEFIG), 'Energy Efficiency – the first fuel for the EU Economy – How to drive new finance for energy efficiency investments', document prepared for the European Commission. More info on www.climatestrategy.com.

Learning from technological developments and RD&D results can result in more effective policies.

International RD&D trends are almost aligned to those of the EU in terms of **energy systems and building renovation, interoperability among systems**, relationships to larger scales **(district and city), behavioural and socio-economic dimensions, and ICT.**

Performance research (including costs and durability) into new products, techniques and publicly funded test infrastructures is required. The change in scale from building to district can result in higher standards for **building renovation**: refurbishment depths should move from the current 9% to beyond 65% (**deep renovation**), while also valuing non-energy-related benefits to make the business models more attractive.

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Annexes

Annex 1: Acronyms and abbreviations

General

CIP	Competitiveness and Innovation Framework programme
CSTB	Centre Scientifique et Technique du Bâtiment
CORDIS	Community Research and Development Information Service
EC	European Commission
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
ERKC	Energy Research Knowledge Centre
EU	European Union
FIRE	Italian Federation for energy efficiency
FP6/7	Sixth/Seventh Framework Programme for Research and Development
H2020	Horizon 2020
IEA	International Energy Agency
IEE	Intelligent Energy – Europe programme
LCA	Life cycle assessment
LCC	Life cycle cost
PB	Policy Brochure
R&D	Research and Development
RD&D	Research, Development and Demonstration
MS	Member States
SETIS	Strategic Energy Technologies Information System
SET-Plan	European Strategic Energy Technology Plan
SWD	Staff Working Document
TRS	Thematic Research Summary

Technical and related to the theme

BIM	Building information modelling
CAs	Concerted Actions
CA EED	Concerted Action for the Energy Efficiency Directive
CHP	Combined heat and power
CPR	Construction products regulation
DEMS	District energy management system
DHC	District Heating and Cooling
DHW	Domestic hot water
DSM	Demand Side Management (Electricity)
E2BA	Energy Efficient Buildings Association
EBC	Energy in Buildings and Communities
ECES	Energy Conservation through Energy Storage
EE	Energy efficiency
EeB	Energy Efficiency in Buildings
EPBD	Recast Energy Performance of Buildings Directive
4E	Efficient Electrical End-Use Equipment
GAHP	Gas absorption heat pump
HP	Heat pump
HPP	Heat Pumping Technologies
HVAC	Heating, ventilation and air conditioning
HVAC&R	Heating, ventilation, air conditioning and refrigeration
IAQ	Indoor air quality
ICT	Information and communications technology
IEQ	Indoor environmental quality
IEA ETN	IEA Energy Technology Network
IEA IA	IEA Implementing Agreement
IVEL	Integrated virtual energy laboratory
LEIT	Leadership in Enabling and Industrial Technologies
MU	Market uptake
NIR	Near infrared
NREAP	National Renewable Energy Action Plan
NZEB	Nearly zero-energy building
PCM	Phase change material
PPP EeB	Public-Private Partnership on Energy-efficient Buildings
reFINE	Research for Future Infrastructure Networks in Europe
RESs	Renewable energy sources
RIA	Research and innovation actions
SHC	Solar Heating and Cooling
STES	Seasonal thermal energy storage

STHS	Seasonal thermal heat storage
VIP	Vacuum-insulated panel
WGBC	World Green Building Council

Annex 2: Complete list of projects relevant to the theme

Sub-theme 1: Public acceptability/acceptance					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
E2ReBuild	Creating added value for existing apartment buildings	FP7 Cooperation – Research Theme: Energy	8.2 total 4.9 EU	www.e2rebuild.eu	2011–14
School of the Future	Towards zero emissions with high performance indoor environment	FP7	4.9 total 3.5 EU	www.school-of-the-future.eu	2011–16
BRITA in PuBs	Bringing retrofit innovation to application in public buildings	FP6 Integrated Project	7.7 total 3.5 EU	www.brita-in-pubs.eu/	2004–08
3ENCULT	Efficient energy for cultural heritage	FP7	6.7 total 4.9 EU	www.3encult.eu/en/deliverables/default.html	2010–14

Sub-theme 2: Nearly Zero-Energy Buildings					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
DIRECTION	Demonstration at European level of innovative and replicable effective solutions for very low energy new buildings	FP7 Cooperation – Research Theme: Energy	6.7 total 4.1 EU	www.direction-fp7.eu/	01/2012 12/2015
BUILDSMART	Buildsmart energy efficient solutions ready for the market	FP7 Cooperation – Research Theme: Energy	8.6 total 4.9 EU		12/2011 08/2015
IEE ENTRANZE	Policies to enforce the transition to nearly zero energy buildings in the EU27			www.entranze.eu	
REHVA survey	NATIONAL Research on zero energy buildings		n.a.	www.rehva.eu/fileadmin/hvac-dictio/05-2012/research-on-zero-energy-buildings.pdf	
NEXT-Buildings	Next zero energy buildings at lowest cost by using competitive sustainable technology	FP7	8.4 total 4.9 EU	www.next-buildings.com	

[44] Budget cost in million Euros represents the total project cost (if available) and the amount funded by the EU or national governments.

Sub-theme 3: New efficient solutions for energy generation, storage and conservation					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
EINSTEIN	Effective integration of seasonal thermal energy storage systems in existing buildings	FP7	9.0 total 6. 2 EU	www.einstein-project.eu	2012–ongoing
HEAT4U	Gas absorption heat pump solution for existing residential building	FP7 EeB.NMP.2011-2 NMP	9.6 total 6.3 EU	www.heat4u.eu/en/	2012–14
RESILIENT	Coupling renewable, storage and ICTs for low carbon intelligent energy management at district level	FP7 EeB.NMP.2011-2 NMP		www.resilient-project.eu	2012–16
E-Hub	Energy-hub for residential and commercial districts and transport	FP7 EeB.NMP.2010-2 New technologies for energy efficiency at district level	11.6 total 7. 9 EU	www.e-hub.org	2010–14

Sub-theme 4: Innovative materials and components for energy-efficient buildings					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
NANOPCM	New advanced insulation phase change materials (PCM) (new buildings)	FP7 EeB.NMP.2010-1	3.5 total 2.4 EU	www.nanopcm.eu	2010–13
COOL-Coverings	Coverings development of a novel and cost-effective range of nanotech improved coatings	FP7 EeB.NMP.2010	4.3 total 3 EU	www.coolcoverings.org	2010–13
NANOINSULATE	Development of nanotechnology-based insulation systems	FP7 EeB.NMP.2010	6.0 total 4.4 EU	www.nanoinsulate.eu	2010–14
AEROCOINS	Aerogel-based composite/hybrid nanomaterials for cost-effective super insulation systems in buildings	FP7 EeB.NMP.2010	4.3 total 3.0 EU	www.aerocoins.eu	2011–14

Sub-theme 5: ICT technologies for energy-efficient buildings and public spaces					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
KnoholEM	Knowledge-based energy management for public buildings through holistic information modelling and 3D visualisation	FP7	4.5 total 3.2 EU	www.knoholem.eu	2011 ongoing
Odysseus	Open dynamic system for saving energy in urban spaces	FP7	3.8 total 2.6 EU	www.odysseus-project.eu	2013–15
ICT4E2B Forum	European stakeholders' forum crossing value and innovation chains to explore needs, challenges and opportunities in further research and integration of ICT systems for energy efficiency in buildings	FP7	1.5 total 0.99 EU	http://eu-smartcities.eu/content/ict4e2b-forum-final-conference www.ict4e2b.eu	2011–13

Sub-theme 6: Energy efficiency improvement of buildings in urban areas					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
CONCERTO	European Commission initiative	FP6 and FP7	175 (58 cities and communities in 22 projects in 23 countries)	http://concerto.eu	From 2005

Sub-theme 7: Tools and measures supporting energy efficiency policy					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
PROFICIENT	SME network business model for collective self-organised processes in the construction and retrofit of energy-efficient residential districts	FP7-2012-NMP-ENV-ENERGY-ICT-EeB	7.3 total 5.5 EU	www.proficient-project.eu	2013 - ongoing
Various projects e.g. IEE ENTRANZE IEE Tabula/ Episcope	Various projects – Market take-up of proven technologies on energy efficiency	CIP Intelligent Energy Europe(IEE) Energy efficiency and rational use of resources (SAVE) and Integrated Initiatives		Search in the Database e.g. search results : Area: Energy efficiency (SAVE) 'building': www.eaci-projects.eu/iee/page/Page.jsp?op=project_list&searchtype=3 e.g. search results: Area: Integrated Initiatives 'retrofit': www.eaci-projects.eu/iee/page/Page.jsp?op=project_list&searchtype=3	2007–13

MURE II database	Mesures d'Utilisation Rationnelle de l'Energie	CIP-IEE Intelligent Energy Europe		www.measures-odyssee-mure.eu	
CA EPBD	Concerted action on Energy Performance of Buildings Directive	CIP-IEE Intelligent Energy Europe 2007–13		http://epbd-ca.eu	2007–10 2011–15
Tabula	Typology approach for building stock energy assessment	CIP-IEE Intelligent Energy Europe 2007–13		http://episcope.eu/iee-project/tabula	2009–12

Sub-theme 8: Environmental control and LCA approach in relation to energy efficiency of buildings					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
CETIEB	Cost-effective tools for better indoor environment in retrofitted energy efficient buildings	FP7	3.5 total 2.5 EU	www.cetieb.eu	2011–14
EeBGuide	Operational guidance for life cycle assessment studies of the energy efficient buildings initiative	FP7	0.9 total 0.5 EU	www.eebguide.eu	
HESMOS	ICT platform for holistic energy efficiency simulation and lifecycle management	FP7	4.6 total 2.7 EU	http://hesmos.eu	2010–13

Projects funded at NATIONAL level:

Sub-themes: Various sub-themes, mainly 1, 2, 4, 6, 7, 8					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
Austria	House of Tomorrow Plus	National Federal Ministry of Transport, Innovation and Technology's research and technology	300 funded through 7 calls for tenders – 35 million Euro granted	www.hausderzukunft.at/english.htm	2010–13
France	Grenelle 2	National	n.a.	www.assemblee-nationale.fr/13/pdf/ta/ta0504.pdf	
	PREBAT R&D Platform on Energy in Buildings	ADEME, ANAH, ANR, Agence nationale pour la rénovation urbaine, Oséo		www.prebat.net	PREBAT: 2011–14

Projects funded at INTERNATIONAL level:

Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
Sub-theme 1: Demonstrating energy efficiency in new and existing buildings					
IEA EBC Annex 50	Prefabricated systems for low energy renovation of residential buildings	IEA EBC – Energy in Buildings and Communities	Funded by participant countries	www.empa-ren.ch/A50.htm	2006–11
SHC Task 47	Renovation of non-residential buildings towards sustainable standards	IEA SHC Solar Heating and Cooling	Funded by participant countries	http://task47.iea-shc.org/	2011-14
SHC task 50	Advanced lighting solutions for retrofitting buildings	IEA SHC Solar Heating and Cooling	Funded by participant countries	http://task50.iea-shc.org/	2013-15
Sub-theme 2: Nearly Zero-Energy Buildings					
IEA EBC Annex 52 – SHC Task 42	Towards net zero energy solar buildings	IEA EBC – Energy in Buildings and Communities IEA SHC Solar Heating and Cooling	Funded by participant countries	http://task40.iea-shc.org/publications	2008–13
Sub-theme 3: New efficient solutions for energy generation, storage and conservation					
IEA ECES Annex 23	Applying energy storage in ultra-low energy buildings	IEA ECES – Energy Conservation through Energy Storage	Funded by participant countries	http://www.iea-eces.org/files/a4.2.1_annex_23_final_report_2014.p http://www.iea-eces.org/files/a4.2.1_annex_23_final_report_2014.pdf	2008-13
Sub-theme 6: Energy efficiency improvement of buildings in urban areas					
EBC Annex 51	Energy efficient communities – case studies and strategic guidance for urban decision makers	IEA EBC – Energy in Buildings and Communities EA	Funded by participant countries	http://www.annex51.org/	2007-11
DHC Task S1	Low temperature district heating for future energy systems	IEA DHC – District Heating and Cooling	Funded by participant countries	http://www.iea-dhc.org/the-research/annexes/2012-2015-annex-ts1.html	2012-15

Sub-theme 7: Tools and Measures Supporting energy efficiency policy					
Project acronym	Project title	Programme	Budget (million EUR) total/funded[44]	Project website	Dates
EBC Annex 56	Cost-effective energy and CO2 optimisation in building renovation	IEA EBC – Energy in Buildings and Communities EA	Funded by participant countries	http://www.iea-annex56.org/	2010-15
Sub-theme 8: Environmental control and LCA approach in relation to energy efficiency of buildings					
EBC Annex 55	Reliability of energy efficient building retrofitting – probability assessment of performance and cost	IEA EBC – Energy in Buildings and Communities EA	Funded by participant countries	http://www.iea-rapretro.org/	2009-13
EBC Annex 57	Evaluation of embodied energy and carbon dioxide emissions for building construction	IEA EBC – Energy in Buildings and Communities EA	Funded by participant countries	http://www.annex57.org/	2011-15

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