EUROPEAN COMMISSION / European Research Area / Energy-efficient Buildings (EeB) PPP

ENERGY-EFFICIENT BUILDINGS PPP

MULTI-ANNUAL ROADMAP AND LONGER TERM STRATEGY

Prepared by the Ad-hoc Industrial Advisory Group

POLICY RESEARCH

Interested in European research?

Research*eu is our monthly magazine keeping you in touch with main developments (results, programmes, events, etc.).It is available in English, French, German and Spanish. A free sample copy or free subscription can be obtained from:

European Commission
Directorate-General for Research
Communication Unit
B-1049 Brussels
Fax (32-2) 29-58220
E-mail: research-eu@ec.europa.eu
Internet: http://ec.europa.eu/research/research-eu

EUROPEAN COMMISSION

Directorate-General for Research
Directorate G – Industrial Technologies
Unit G2 – New generation of products
E-mail: jose-lorenzo.valles@ec.europa.eu; christophe.lesniak@ec.europa.eu
Internet: http://ec.europa.eu/research/industrial_technologies

EUROPEAN COMMISSION

ENERGY-EFFICIENT BUILDINGS PPP

MULTI-ANNUAL ROADMAP AND LONGER TERM STRATEGY

Prepared by the Ad-hoc Industrial Advisory Group

Directorate-General for Research, Industrial Technologies
2010 Unit G2 'New generation of products' EUR 24283 EN

EUROPE DIRECT is a service to help you find answers to your questions about the European Union

Freephone number (*):

00 800 6 7 8 9 10 11

(*) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

LEGAL NOTICE

Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of the following information.

The views expressed in this publication are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server (http://europa.eu).

Cataloguing data can be found at the end of this publication.

Luxembourg: Publications Office of the European Union, 2010

ISBN 978-92-79-15228-3
ISSN 1018-5593
doi:10.2777/10074

Printed in Belgium

PRINTED ON WHITE CHLORINE-FREE PAPER

TABLE OF CONTENTS

1.0 INTRODUCTION 5
2.0 THE ROADMAPPING PROCESS 7
2.1 Strategic objectives, drivers and pillars 7
2.1.1 Strategic objectives 7
2.1.2 Trends and elements of future scenarios 7
2.1.3 Key pillars of the Roadmap 11
2.2 The methodology and large involvement of stakeholders 13
3.0 RESEARCH CHALLENGES 17
3.1 Key challenges for a long term strategy 17
3.2 Research challenges at the basis of a multi-annual Roadmap 18
3.2.1 Refurbishment to transform existing buildings into energy-efficient buildings 21
3.2.2 Neutral/energy-positive new buildings 22
3.2.3 Energy-efficient districts/communities 23
3.2.4 Horizontal technological aspects 25
3.2.5 Horizontal organisational aspects 29
4.0 ASSOCIATED INVESTMENTS AND QUANTIFIED EXPECTED IMPACT 33
5.0 DEFINITION OF A MULTI-ANNUAL ROADMAP 37
6.0 INTERNATIONAL COOPERATION 41

Appendix 1: First calls for proposals published in the Work Programme 2010 43
Appendix 2: Expected socio-economic impacts and relevance to policy objectives 43

LIST OF TABLES

Table 1: Proposed Roadmap for 2011-2013 39

LIST OF FIGURES

Figure 1– Energy use in residential (left) and commercial buildings (right) 10
Figure 2 – Wave action along the multi-annual Roadmap 12
Figure 3 – Key research areas targeting the challenges at the basis of the long term strategy ... 14
Figure 4 – Overview of the methodology to identify future research priorities 15
Figure 5 – VENN diagram showing inter-relationship among research challenges 20
Figure 6 – The multi-annual Roadmap (2011-13) within the longer term "wave action" strategy 38

CONTRIBUTORS TO THIS DOCUMENT

In the following list the members of the Ad-hoc Industrial Advisory Group who have contributed to the preparation and editing of the document are reported, but many other contributors have provided their views during an open consultation process.

Acciona (ES): Javier Grávalos, José Javier de las Heras
ACE/CAE (BE): Adrian Joyce
Apintech (GR): Nikos Sakkas
Arup (UK): Rupert Blackstone, Marta Fernández, Jeremy Watson
Atos Origin (ES): Ignacio Soler Jubert
BIC (SE): Ake Skarendahl
Bouygues Construction (FR): Paul Cartuyvels, Frédéric Gal, Alain Vassal
BSRIA (UK): Andrew Eastwell
Centro Ceramico Bologna (IT): Arturo Salomoni
ClimateWell (SE): Mats Fällman
CSTB (FR): Luc Bourdeau, Alain Zarli
D'Appolonia (IT): Stefano Carosio (Coordinator), Guido Chiappa, Raimondo De Laurentiis, Mattia Fabbri, Nicolò Olivieri, Sergio Segreto
ECN (NL): Ivo Opstelten
EDF (FR): Alain Marti
Fraunhofer – IBP (DE): Roland Göttig, Gerd Hauser
Labein/Tecnalia (ES): Jose Maria Campos
Mostostal (PL): Juliusz Zach
OHL (ES): Miguel Arenas Cuevas
Philips (NL): Bruno Smets
Saint-Gobain (FR): Roger De Block, Jean-Marie Thouvenin
SAP (DE): Silvio Semprini
Schneider Electric (GR): Polydefkis Loukopoulos
Solintel (ES): J. Antonio Barona
Stiebel Eltron (DE): Holger Thamm
Telefonica (ES): Enrique Fernando Menduiña
TNO Built Environment and Geosciences (NL): Olaf Adan
VTT (FI): Matti Hannus, Markku Virtanen
ZRMK (SI): Marjana Sijanec
Züblin AG (DE): Rainer Bareiß, Norbert Pralle

1.0 INTRODUCTION

The Energy-efficient Buildings (EeB) PPP, launched under the European Economic Recovery Plan[1], will devote approximately € 1 billion in the period 2010-2013 to address the challenges that the European construction sector and its extended value chain are facing in their ambitious goal of researching new methods and technologies to reduce the energy footprint and CO_2 emissions related to new and renovated buildings. This represents the initial and highly strategic step of a longer term set by the industry to create more efficient districts and cities while improving the quality of life of European citizens.

The preparation of this multi-annual Roadmap has been driven by industry in the framework of an Ad-hoc Industrial Advisory Group. The private sector was represented by the European "Energy-efficient Buildings Association"[2] (E2BA), as industrial interlocutor of the European Commission in the EeB PPP. The dialogue with European Commission officials from DG RTD (for Themes NMP and ENV), DG TREN and DG INFSO already allowed to provide industrial input for the preparation of the Coordinated Call included in the Work Programme 2010, which is mentioned in Appendix 1. In 2010 these activities will already mobilise around € 65 million of EC funding within the overall financial envelope of € 1 billion, to be contributed in equal shares by the private sector and the European Commission under the Seventh Framework Programme for Research (FP7).

The scope of this document is to present the list of research priorities for the definition of a long term strategy and a Multi-Annual Roadmap, as identified by industry in the framework of the European "Energy-efficient Buildings Association " (E2BA) and beyond, through its multiplier effect within the broader stakeholder community. In Chapter 2 the main drivers, pillars and strategic objectives at the basis of the Roadmap are presented jointly with the methodology designed for the definition of the research priorities capable of mobilising innovative and high impact projects.

In Chapter 3 the research challenges in the long term are presented, including all those horizontal non-technological aspects which are instrumental to generate the expected impact in an enlarged Europe. Chapter 4 provides an overview of the investments associated with the broader implementation of the Roadmap and its research priorities as well as a quantification of the expected impact both from the economic, environmental, social and policy point of view, highlighting for instance contributions to job creation and the implementation of the SET Plan.

Chapter 5 provides Research Priorities within the framework of the EeB PPP initiative. The definition of the priorities was based on the relevance of each challenge towards the reduction of energy consumption in the built environment and the associated decrease in greenhouse gas emissions (GHG) as well as the expected impact when addressing the challenge itself, fully in line with the provisions of the European Economy Recovery Plan. The elements of the Roadmap till year 2013 are provided, as initial research priorities to be considered within FP7, in line with the longer term industry strategy.

1. European Economic Recovery Plan COM(2008) 800
2. www.e2b-ei.eu

2.0 THE ROADMAPPING PROCESS

2.1 Strategic objectives, drivers and pillars

2.1.1 Strategic objectives

The construction sector accounts for 30% of industrial employment in the European Union, contributing about 10.4% of the Gross Domestic Product, with 3 million enterprises, 95% of which being SMEs[3]. Overall 48.9 million workers in the EU depend, directly or indirectly, on the construction sector[4] Within the construction market, the buildings industrial sector (residential and non-residential) is the largest economic sector, as their construction and refurbishment account for 80% (€ 1,200 billion) of the total construction sector output (€ 1,519 billion)[5] of EU27 in 2007. Every day, the construction sector in the EU builds or renovates thousands of places where people work, live, spend their leisure time or rest. Today, the construction sector is fully aware of a huge responsibility, **being the highest energy consumer in the EU (about 40%)**[6] **and main contributor to GHG emissions (about 36% of the EU's total CO_2 emissions and about half of the CO_2 emissions which are not covered by the Emission Trading System).**[7] In March 2007, the European Council set clear goals for 2020:

- Increase energy efficiency to achieve a reduction of 20% of total energy use (below 2005 levels);
- 20% contribution of Renewable Energies to total energy use (11.5% above 2005 contribution);
- 20% reduction of Greenhouse Gases (GHG) below 1990 emissions (14% below 2005 emissions)[8].

In line with the European Economic Recovery Plan, further strategic targets impacting on Energy Efficiency in Buildings and its innovation potential are associated to the following policies:

- the EU Lisbon Strategy for Growth and Jobs;
- the Barcelona 3% RTD intensity objective;
- the Recast of the Energy Performance of Buildings Directive;
- the Action Plan on Energy Efficiency in Europe – saving 20% by 2020;
- the Directive on end-use energy efficiency and energy services;
- the White book on Renewable Energy Sources (RES);
- the Action Plan on Energy Efficiency – "Doing More with Less";
- the Directive on electricity from renewable energy sources;
- the Directive on eco-design of end-use energy consuming equipment;
- the Directive on appliances energy labeling;
- the Directive on heat demand based high efficient cogeneration;
- the European Strategic Energy Technology Plan;
- the Environmental Technology Action Plan;
- the EU Sustainable development strategy;
- the Green paper towards a European strategy for the security of energy supply;
- the Kyoto Protocol and related international agreements;
- the i2010 Strategy and Communication.

2.1.2 Trends and elements of future scenarios

This document, identifying research priorities for the next future, is part of a longer term road-mapping exercise. The vision for this Roadmap is built on the E2B Scope and Vision document[9], where the following statement is formulated: "By 2050, most buildings and districts could become energy neutral, and have a zero CO_2 emission. A significant number of buildings would then be energy positive, thus becoming real power plants, integrating renewable energy sources, clean distributed generation technologies and smart grids at district level."

3. FIEC – European Construction Industry Federation. http:\\www.fiec.org\
4. Communication from the Commission " The Competitiveness of the Construction Industry", COM(97) 539 of 4/11/1997, chapter 2
5. Euroconstruct 2007
6. EU Energy and transport in figures, statistical pocket book 2007/2008.
7. Proposal for a recast of the EPBD, Impact Assessment. COM(2008)755, SEC(2008)2821
8. Targets elaborated within the document E2B Impact Assessment, Version 2, February 2009
9. European Initiative on Energy-efficient Buildings, Scope and Vision, Version 1, January 2009

Looking at energy use, the following example scenarios for building schemes in 2050 could be identified:

Areas of high residential and work density with the following characteristics:

- **>** Electricity generated elsewhere by means of renewable and/or CO_2-free sources is used with high efficiency.
- **>** Sustainable electricity, heat and cold are generated on the spot at building level and district level.
- **>** Gas (methane[10] and/or hydrogen) is an option where the combined demand for heat and electricity makes this "exergetically"[11] attractive, using advanced burners and fuel cells.
- **>** Active gas connections are few and far between, relatively expensive and in practice only found at major users and 'energy routers' (energy hubs at 'district' level); they are connected to large storage systems, and in most places the hub also functions as a 'filling station', for instance for local transport.
- **>** Local energy management is taken for granted and small-scale energy buffering (thermal and electrical) is used on a large scale to optimise cost.
- **>** The word 'cost' now relates to both internal and external factors, making optimisation simple and socially worthwhile. Energy prices and revenues are highly differentiated (by time and type) to enable the now complex energy system to be run economically.
- **>** Indoor thermal comfort is guaranteed, coping with heat islanding and dense population.
- **>** Energy usage will be measured in terms of user comfort, performance and added value to the involved stakeholders through advanced performance-based business models.

Park city areas with the following characteristics:

- **>** Sustainable power generation on a large scale, at building level and district level, with some producers even being net exporters of electricity.
- **>** The demand for heating and cooling is met entirely from solar and renewable energy generated, captured and stored locally.
- **>** Solar energy is an integral part of architecture (buildings and infrastructure).
- **>** Energy management and buffering (thermal and electrical) are commonplace.
- **>** Gas (methane and/or hydrogen) is used almost exclusively by energy routers.

Thinly populated areas with the following characteristics:

- **>** Function as park cities, except that there are no energy routers.
- **>** A large amount of generation, e.g. various types of solar power stations and wind farms linked to the built environment. Major exporters of electricity.

Historic areas with the following characteristics:

- **>** Can function as any other type of areas, except that the visible parts of the built environment are protected implying that energy measures should not alter the appearance of those parts and the needs of conservation of materials and objects have to be respected.
- **>** The buildings often have a very specific energy signature (churches, museums, etc.), distinctly different from the main part of the building stock.

These future scenarios are duly considering both commercial buildings and residential housing which, based on today's data, represents the 63%[12] of the energy consumption of the European building stock.

10. Methane can take the form of natural gas or be produced from biomass.
11. Exergy is useful when measuring the efficiency of an energy conversion process. The ratio of exergy to energy in a substance can be considered a measure of energy quality. Forms of energy such as kinetic energy, electrical energy, and chemical Gibbs free energy are 100% recoverable as work, and therefore have an exergy equal to their energy. However, forms of energy such as radiation and thermal energy can not be converted completely to work, and have exergy content less than their energy content.
12. http://ec.europa.eu/environment/integration/research/newsalert/pdf/48na1.pdf

Trends in the building stock: natural mutation moments

The rate of change of the built environment from an energy consumer towards an energy producer is directly linked to the intervention moments, often referred to as natural mutation moments. These are: 1) Renovation of energy infrastructures; 2) New building additions; 3) Refurbishment; 4) Large maintenance; 5) Heating, Ventilation and Air Conditioning (HVAC) system replacement; 6) Demolition.

Within the 160 million residential and commercial buildings in Europe, the current housing stock can be roughly divided into 16 categories, ranging from terraced houses built in various eras to flats and detached houses. The percentage of owner-occupied highly varies across Europe, from less than 50% in Western European countries to more than 90% in some of the new member states. As regards the built environment, scenario studies expect a migration towards the cities (densely populated and park city areas), with the number of members in each household declining. This implies a net growth of the housing stock at least towards 2030. The annual growth rate of new buildings added to the housing stock is currently estimated at around 1-1.5% of the housing stock. The number of buildings removed from the stock is about 0.2-0.5 % of the housing stock a year. It is assumed that this trend will continue in the period ahead. The number of refurbishments accounts for roughly 2% of the housing stock a year. Each year, heating systems are replaced in about 5% of the building stock. The same natural mutation applies to the non-residential buildings, although at different rates per year, depending on the type of building (school, office, hospital, store, etc.).

Consumer and demographic trends

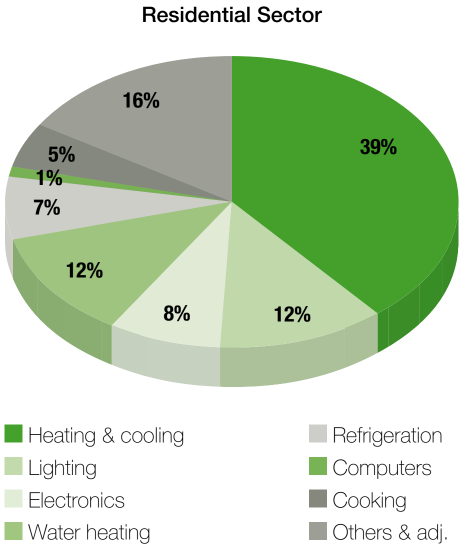
Consumers are becoming increasingly demanding, especially as regards level of comfort, as can be seen from the rising numbers of domestic appliances and the quality of the indoor environment that consumers expect (moisture, undesirable substances, etc.). Another factor here is that around 1 in 5 households includes an occupant with a diagnosed respiratory condition, and the medical expenses for these people run to an estimated € 250 per household a year, for the EU amounting to approximately € 14 billion a year. The population is ageing, with the number of over-65s expected to rise from the present 12% to over 25% during the 2030-50 period. This could affect the demand for energy. Flexible working is also on the rise, with an increasing share of the population working at home. The number of households is continuing to rise as they become smaller in size.

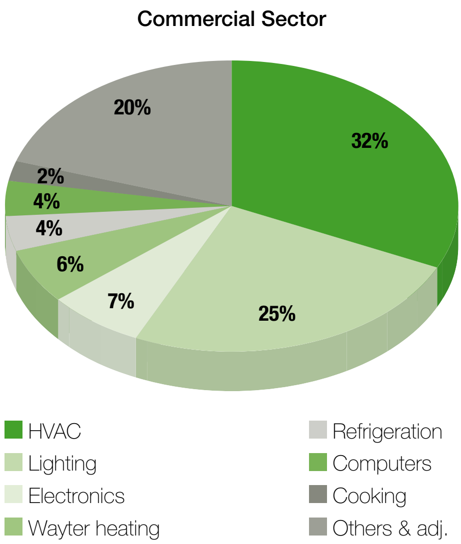
Trends in the demand for energy in the built environment and supply

Today, primary energy use in the built environment accounts for about 40% of total EU energy consumption. In residential buildings most of the energy used is required for domestic hot water and space heating, ventilation, lighting and cooling. Non-building-related appliances[13] account for about one-third of electricity consumption in housing, as shown in Figure 1 below.

13. Electricity is used for cleaning, audio/video/communication, cooking, kitchen appliances, indoor climate control, hobbies, personal care and a miscellaneous category.

Figure 1: Energy use in residential (upper) and commercial buildings (lower)[14]





The demand for electricity is expected to rise, owing to the increasing use of appliances, demand for cooling and number of households. The demand for space heating is expected to fall as a result of further demand-limiting measures and increasing electricity consumption. This means that heat will be supplied to homes mainly for hot water. All in all it becomes a necessity to strengthen the power grid.

Commercial buildings are an electricity-demand-based environment (accounting for over 33% of primary energy use). Heat is a minor factor here; what is required mainly is cooling. Lighting is another major energy user. The electricity demand is expected to continue to rise, in particular owing to increasing use of appliances and demand for cooling. As regards supply (of energy-related technologies), the main finding is that the number and variety of energy generation systems for use in the built environment is large and seems to be constantly increasing. It should be noted, however, that it is not the case that all these technologies are sold in equally large quantities. Because of security of supply reasons, in the coming years the mix of primary energy sources will change, which in some aspects will also influence the type of energy generation systems in the built environment, specifically towards an increasing share of decentralised production.

Governmental trends

Governments are involved in the built environment in all sorts of ways. Government policy on the built environment directly affects energy demand to some extent. So far policy has focused on reducing building-related consumption in the new building area (by means of Energy Performance Standards). For domestic appliances there are energy labels to encourage consumers to buy energy-efficient appliances. We have already recalled in Chapter 1 the main targets associated with the recent European Council decisions, setting the scene up to 2050. Targets are also set in the recast of the Energy Performance of Buildings Directive[15], in particular as far as Public Buildings are concerned, as well as in the Eco-design and Energy services directives. Government policies on e.g. comfort, air quality, local mobility and noise also indirectly affect

14. DoE Building Book 2008
15. CEC, "Proposal for a Directive of the European Parliament and of the Council on the Energy Performance of Buildings (recast)", 13.11.2008

energy performance in the built environment. The general national, and certainly international, trend is for standards to be raised constantly. As the built environment is required to meet various types of standards, the regulations relating to it are accordingly complex (building regulations, directives on noise and moisture levels, energy performance, etc.). Although governments are looking at ways of deregulating, we shall still have to contend with a whole host of standards, rules, procedures, etc. in the built environment. Local authorities also have an effect on trends in the built environment: by setting out aspirations for estates/buildings that are to be developed they determine what happens to a large extent, and this takes place at a very early stage.

Scarcity of resources

Europe is facing an increasing scarcity of raw material supply in various fields. In order to reduce the energy and carbon burden linked to building materials and components, Europe will see an increasing pressure on their sustainable performance, i.e. longer service life, multi-functionality as a primary step to create added-value of material use, more efficient use of primary raw materials, an increase in recycling as well as an increasing use of renewables. In addition, the application of lightweight materials and systems will be inevitable to reduce the environmental impact of the construction process. Particularly with respect to the last two issues, the scarcity of resources will be a restraining factor. As energy demand for the operational phase of the building life cycle is decreasing and/or for a larger part covered by renewable energy, the embodied energy of building materials and components will become an increasingly important aspect to take into account. The present ratio between embodied energy and energy during the use phase of a building is about 20/80.

Industrial/Commercial trends

An enormous diversity of commercial operators is involved in the built environment. Housing associations, developers, suppliers of components or subsystems, contractors/builders, service providers, all of these play a role in the decisions taken to design, build, occupy etc. buildings. The most important decisions are made early on in the building process. Therefore, after local authorities, it is mainly developers and housing associations that are responsible for them. Most suppliers of building units and subsystems are highly short-term-oriented, not looking any further ahead than five years at most, generally speaking. As the building contracting industry itself is highly national, many commercial operators also have a strong focus on the domestic market. Suppliers, however, are increasingly becoming international. Because of the way the building industry is organised, decision-makers/investors in e.g. energy saving or sustainable energy are not the ones who benefit from the gains that these can provide. As a result of this imbalance, market forces do not provide any strong incentives towards Life-Cycle-Costing for buildings, and breakthroughs are only likely if regulations are also set in place. Because cost optimisation is to a large extent linked with optimisation of the required amount of man-power, more and more use will be made of prefabrication and ICT (e.g. Building Information Models) in the building process.

2.1.3 Key pillars of the Roadmap

The challenges the sector faces are too complex to be solved by a single uniform action. Furthermore the EU's buildings sector is a true example of the EU's diverse nature. For example, looking just at the integration of renewable energies in the built environment will not in itself be sufficient to decrease Europe's energy dependence. In a similar way, retrofitting buildings one by one will never solve climate change problems. These are some of the reasons why we also need to adopt a **holistic approach**, considering technological aspects, technology integration (targeting both the buildings and the broader urban environment) as well as the user as the key for successful impact.

Working at district level, or on large groups of buildings, is certainly the true scale identified within the long term strategy by E2BA[16] and it is fully reflected in the design of the long term Roadmap. Only district scale intervention will permit the achievement of the much higher energy efficiency targets required by optimising the use of energy at different levels:

16. www.e2b-ei.eu

> whole district (networks and grids, street lighting and signalisation, urban heat production..);
> groups of dwellings (sharing and managing energy production, social attitudes, involving public owners…);
> residential and non-residential building level (insulation, building energy management systems, high performance energy systems, integration of renewables,…);
> other synergies at the regional or national level or in areas with similar climatic characteristics.

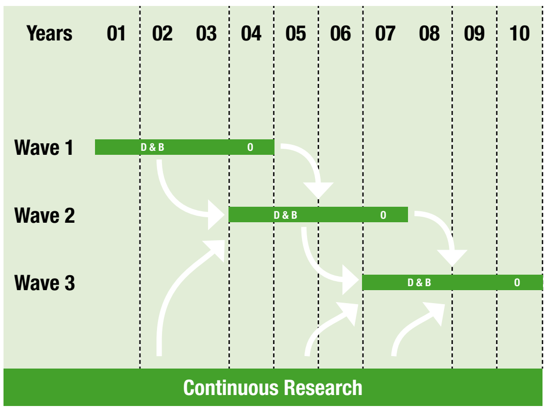
One of the fundamentals of the long term strategy is that energy efficiency will respond to climate change and energy issues, providing we are able to trigger large scale actions concerning all Member States. Different climates, building traditions and cultural, historic and economic factors have resulted in significant variations between the EU Member States and even between their regions. We observe that 20 European Member States have specific policies and measures addressing climate change for the Building Sector, 8 Member States have launched RD&D actions in the building sector, 14 Member States have developed educational measures, 3 Member States propose public investment measures, 15 Member States propose financial instruments and incentives/subsidies while 16 Member States propose regulatory instruments. In order to generate an impact, our Roadmap addresses therefore the **concept of "geo-clusters"**, conceived as virtual trans-national areas/markets where strong similarities are found, for instance, in terms of climate, culture and behaviour, construction typologies, economy and energy/resources price policies, Gross Domestic Product, but also types of technological solutions (because of local demand-supply aspects) or building materials applied, etc.

Our Roadmap is therefore based on a holistic approach, contributing to a proper integration of specific solutions developed in the various technical fields to form a coherent, global solution. In this framework, the Roadmap has been built on **pillars**, such as: 1) **systemic approach**; 2) **exploitation of the potential at district level**; 3) **geo-clusters**. As a result, the Roadmap will fully leverage on the GOLD rule: Globally Optimised, Locally Designed.

Fast implementation and performance feedback represent a major element in building up the long term strategy and the multi-annual Roadmap within the EeB PPP. Monitoring and proper reactive actions are then major components. Both are included in what industry has called a **"wave action"**. In this "wave action" plan, continuous, on-going research feeds successive waves of projects as stated here below. The knowledge gained in the first "wave" feeds into the second at the design stage, realising a continuous implementation process. The Roadmap is based therefore on the following logic:

> continuous, on-going research feeding successive "waves" of projects (Design&Building followed by Operation) as stated here below;
> knowledge gained in the first "wave" feeding also the second at the design stage, realising a continuous implementation process (see Figure 2 below).

Figure 2 - Wave action along the multi-annual Roadmap



Within a ten year time perspective, three waves will have been completed. A movement will have been started and other waves of implementation will follow. Clearly in our vision and ambition the work will not stop after ten years. As a result of this "wave action" we expect to achieve an impact following a stepped approach, namely:

> **Step 1: Reducing the energy use of buildings and its negative impacts on environment;**

> **Step 2: Buildings cover their own energy needs;**
> **Step 3: Transformation of buildings into energy providers, preferably at district level.**

It is the objective within the EeB PPP to focus the multi-annual Roadmap mainly on the first step of the longer term strategy, namely “Reducing the energy use of buildings and its impacts on environment”. Nevertheless, the multi-annual Roadmap will also tackle the development of the enabling knowledge and technologies (e.g. demand reduction, renewable energy production and energy storage through multidisciplinary research efforts) which are instrumental for the more ambitious Step 2 and Step 3 objectives, launching the required more fundamental and applied research actions. This further justifies the logic of a continuous research activity along the Roadmap itself.

2.2 The methodology and large involvement of stakeholders

This chapter provides an overview of the methodology which has been used for the identification of the research priorities by the AIAG, in a broad consultation within E2BA and the enlarged network of stakeholders. This constitutes the basis of a long term strategy and the multi-annual Roadmap up to 2013, the focus of this document. Through the E2BA members and their multiplying effects, a large community of Local Authorities, Capital Providers, Developers (Designers, Engineers, Contractors), Supply chain (Materials and Equipment Suppliers), Investors and Owners as well as End Users have been reached, providing a broad overview of the research needs for the future of the sector. Indeed, over 200 contributions highlighting research challenges and opportunities have been gathered from more than 100 E2BA member organisations, organised in five Working Groups. An in-depth analysis of Strategic Research Agendas, Implementation Plans and relevant R&D Position Papers from running European Technology Platforms (ETPs) and Joint Technology Initiatives (JTIs) was performed in parallel. This was duly confronted with other relevant European Initiatives, such as the Roadmaps of the Industrial Initiatives or the SETIS Information System within the SET Plan. This allowed the building up of a taxonomy which globally maps the European R&D priorities landscape, relevant to Energy-efficient Buildings.

These two parallel exercises demonstrated a powerful synergy and have been very important in the identification of Research Priorities. More than 1700 inputs from relevant European Initiatives of potential interest for energy-efficient buildings have been identified. The inputs collected from the E2BA members have been compared with research priorities identified from the analysis of the Strategic Research Agendas, Implementation Plans and relevant R&D Position Papers, as a cross-check that relevant research challenges for the sector were not missed. Further major initiatives have been considered, for instance the recent **“Vision and Research Roadmap” from the International Energy Agency**[17] or the latest report on **“Energy Efficiency in Buildings” from the World Business Council for Sustainable Development**[18], to name but two. Previous work from **DG INFSO's "Ad-Hoc Advisory Group Report on ICT for Energy Efficiency" as well as the available results from the project REEB “Strategic research Roadmap to ICT enabled energy-efficiency in buildings and construction”** has been duly taken into account. An in-depth analysis and clustering exercise has been performed on the research gaps and challenges gathered during this initial phase. Key criteria for selection were:

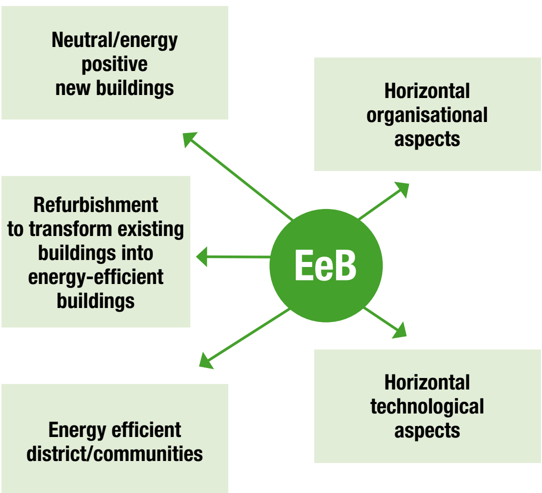
> Impact, intended as the expected contribution to reduce energy use and greenhouse gas Emissions in the built environment as well as the potential to increase competitiveness of the stakeholders in the value chain, including tangible social and economic benefits for the end-users (e.g. reduction of the energy bill);
> Innovation Potential, intended as the opportunity to introduce new scientific and technological advancements for the sector which may trigger the development of novel knowledge-based products, processes and services, including sustainable business models and policy instruments that can mobilise user acceptance;
> Time to market, intended as the time frame for the take-up of results and the introduction of the technological and non-technological innovations in the market;

17. “Vision and Research Roadmap for Future Sustainable Buildings and Communities”, IEA, Final version, 9.9.2007
18. “Transforming the market: Energy Efficiency in Buildings” WBCSD, 2009

- Geo-clusters, intended as the added value to tackle the challenges at EU level, clustering different climatic areas, business cultures and value chain practices, to name a few, thus securing that globally optimised technical solutions and policy tools may be adaptable to local specificities, while securing EU technological and economic competitiveness (including IPR leadership);
- Investments/Funding requirements, intended as the resources needed to address the technological and non-technological challenges, proportional to the ambition of the underlying scientific developments and the need to deploy large demonstration programmes to ensure replicability;
- Inter-disciplinarity, intended as the need to combine different scientific and non-technical disciplines to address the specific challenges, in line with the overall goal of the EeB PPP initiative.

Five major areas have been identified, each grouping several research challenges. The overall scenario is graphically presented in Figure 3 below.

Figure 3 – Key research areas targeting the challenges at the basis of the long term strategy



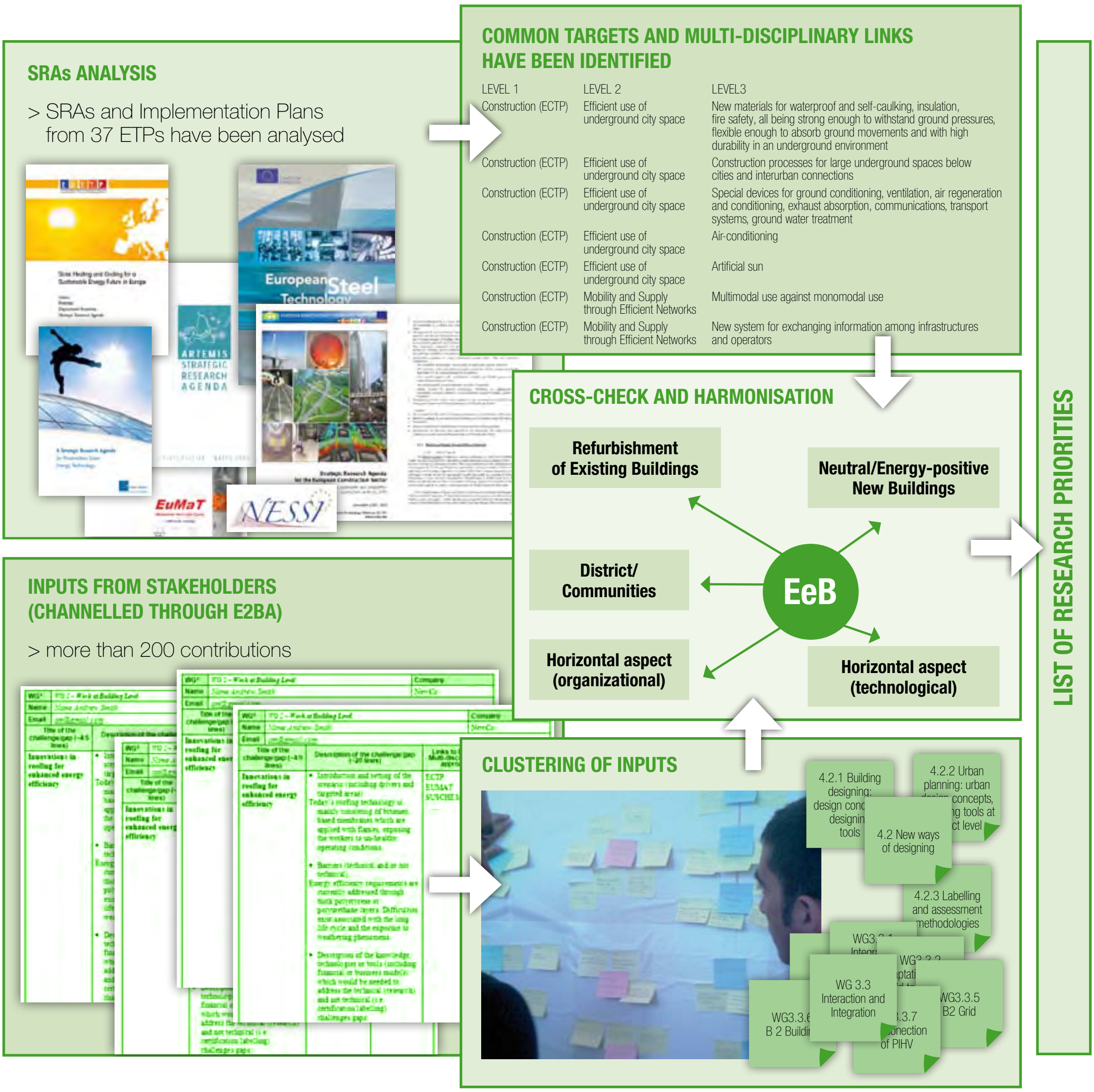
It is worth noting the relevance of non-technological challenges in the overall strategy, being user acceptance, build up of a value chain, availability of new business models and proper policy instruments, to name a few, highly important. These are drivers that are crucial for successful implementation and a paradigm shift, definitely benefiting from benchmarking both across enlarged Europe and the world.

Indeed, in building up the Roadmap, special attention has been given to horizontal aspects and not just technological barriers, in line with the document of the Lead Market Initiative for EU, "Accelerating the Development of the Sustainable Construction Market in Europe". On these topics, Europe has launched actions and programmes such as ECO-BUILDINGS (more than 100 projects from FP5, FP6 and FP7 in many different European cities) CONCERTO (18 projects from FP6 and FP7 covering 46 different CONCERTO communities), SAVE projects, the ERA-NET initiative "ERACOBUILD" as well as national programmes. By addressing the identified transversal aspects, the proposed approach has duly taken them all into account either supporting the implementation of already obtained results or by developing coherent, complementary actions.

In this framework, the structured approach tackles all relevant domains to increase cost effectiveness, improve performance and remove technical and market barriers, developing a holistic strategy and generating appropriate business models to address economic, social and environmental requirements at building and district level.

A quali-quantitative ranking of the research challenges towards the objectives of the EeB PPP has been made at AIAG level, giving priorities in terms of implementation. The overall methodology at the basis of the identification of research challenges and priorities is presented in Figure 4.

Figure 4 – Overview of the methodology to identify future research priorities



A more detailed presentation of the research challenges and priorities, covering both technological and non-technological aspects, is presented in the following Chapters.

3.0 RESEARCH CHALLENGES

3.1 Key challenges for a long term strategy

In a context of meeting ambitious targets for improving energy independence and for fighting against climate change, the long term goals are surely towards low energy and energy positive buildings/districts which require new knowledge and technologies to overcome current limitations. Nevertheless, several research challenges need to be addressed for a sustainable strategy for energy-efficient buildings, such as:

- Definition of **energy-efficient solutions for renovation**. Many innovative solutions are directed towards new buildings but only a few are optimised for the existing stock. Moreover, buildings, especially residential buildings, are never considered as a whole. Therefore, there are a lot of components (windows, insulation materials, boilers, lighting, etc.) which are installed, serviced and maintained by different companies without a holistic approach to the overall building operation. The result is a lack of energy efficiency and in some cases functionality once the buildings are refurbished. R&D has to propose integrated solutions taking into account the various constraints of existing buildings. It is assumed that the developments of many innovative solutions (systems composed of insulation and thermal storage materials, renewables, etc.) are relevant for the countries all over Europe.
- There is also a need for **acceptability by customers** which means that 1) each behavioural strategy must be clear as to the associated technology (e.g. encouraging people to avoid overheating in winter would be supported by effective, intelligible heating controls) and 2) each technology must be thought through in terms of the behavioural correlates (e.g. whether energy-efficient ventilation will actually be used) and opportunities (to encourage behaviour change while delivering the technology). The outcome of research into understanding barriers and drivers for non-technical (e.g. behaviour) and technical aspects, such as the development of multifunctional solutions (e.g. eco-efficiency, comfort, aesthetic value…), would speed up the transformation of the market. **Cost savings** can also help greatly in supporting the development of the energy efficiency market. Price being one of the major drivers for the customers, R&D together with deployment has to reduce drastically the cost of certain technologies (market of hundreds of thousand of units), such as heat pumps, photovoltaics or emerging lighting solutions, to name a few. There is also a large **potential for an increase of performance** from the economic and CO_2 point of view. Heat pumps have an operational coefficient of performance of around 3 today, and they could move to 4 and higher in the coming years. Furthermore, as example, an additional 30-40% energy saving for lighting could be achieved by adding intelligence to modern systems.
- **Market transformation** shall indeed be researched and investigated. Low carbon technologies have to move from a several-hundred-thousands to a multi-million-unit-per-year market. **Financing issues** also need to be tackled, jointly implementing new **business models** and services with a life cycle perspective.
- **Building industry transformation has to be achieved**. The gaps are on systemic approaches for refurbishment, building design and quality of installation. Due to the complexity of the situation (different components to be assembled in order to minimise the investment, the running cost and the CO_2 emission), there is a real need to develop new codes, and to provide new tools and guidelines to the building industry. There is also a need to develop solutions suitable for use by the construction industry: affordable packaged solutions or kits which are

easy to install. Europe will thus develop a competitive industry, from component manufacturers to installers and a broader range of knowledge-based service providers.

Obligations and incentives might be successful in producing results, but, for a more effective strategy in Europe, the Regulators and the Companies should address R&D innovation in combination with marketing efforts and information campaigns: **"From Obligations & Incentives to Information & Innovation"**.

3.2 Research challenges at the basis of a multi-annual Roadmap

In order to address the challenges ahead and accomplish the strategic vision highlighted, a number of research areas have been identified, as detailed in Figure 3, namely:

1. **Refurbishment to transform existing buildings into energy-efficient buildings**, where breakthroughs are searched for in more efficient solutions for insulation or low carbon integrated systems with low renovation cost (50% of a new building). Opportunities exist to improve the energy performance of most of the existing buildings, reducing the thermal energy demand and increasing the renewable energy production. A wide improvement in energy demand is possible, moving from more than 300 kWh/m^2 to 50 kWh/m^2 per year. The impact in terms of decrease of energy use and CO_2 will be strong, considering that in Europe 80% of the 2030 building stock already exists and today 30% of existing buildings are historical buildings. If we consider indeed the retrofitting of historical buildings, the technologies are today mainly devoted to monitoring the movable and fixed works of art instead of control of the energy use or environmental pollution reduction. In this case the retrofit must respect the integrity, authenticity and compatibility between the old and the new materials and techniques.

2. **Neutral/Energy-positive new buildings**, where breakthroughs are required in new efficient, robust, cost effective and user friendly concepts to be integrated in new buildings, in order to increase their energy performance, reducing energy use and integrating RES. Today the efforts focus mainly on local energy generation (integrating for example massive PV, micro generation, etc.) without taking into account the global energy efficiency of integration in buildings. Technologies and methods exist to build neutral or energy positive buildings, able to produce more energy that they use, although the efficient exploitation of resources within a life cycle perspective or the conception of adequate business models are often not addressed. Renewable energy production potential is going to be sufficient for new low-rise buildings to keep a neutral energy balance. Implementation onto high rise buildings will, however, require new breakthroughs. Combined with PV-efficiency improvements, building-integrated PV could double the current contribution of energy positive houses. Better knowledge of the spectral solar radiance (the radiation at different incident and azimuth angle under different weather conditions) is required, as this may impact both energy production as well as thermal energy absorption/reflection, enabling the development of new multifunctional concepts. Novel contracting models which take into account the positive balance in energy management are needed, including performance, duration of high level of performance, maintenance, etc. (see continuous commissioning).

3. **Energy-efficient districts/communities**, where innovation is required to enable new methods of addressing the difference in dynamics of energy supply and demand, in the diversity in energy demands (magnitude and type: heat, cold, electricity), in the energy losses in distribution of thermal energy, in the difficulty to split the incentives, in the difficulty to operate in existing buildings and districts and in the current absence of exchange/sharing of energy by different decentralised suppliers. The creation of a system that can adjust to the needs of the user by analysing behaviour patterns will raise the overall performance of buildings and districts. For this to happen, the design of systems should re-orient from centralised control logic of the whole building to localised control of individual rooms with communication between control-

lers. Opportunities exist for low-energy or energy-positive districts. Coupling of centralised and decentralised solutions for peak shaving, the renewable energy share and the thermal and electrical energy storage can be developed in order to increase the energy matching potential across different energy demand inside the district (e.g. heat, cold, electric energy and energy needed for public and private transport). Efforts to implement "low-exergy system approaches" are needed which try to minimise the temperature differences in the system (e.g. solar collectors + heatpump + floor heating/cooling), in order to optimize the overall system efficiency. New markets and services related to energy exchange/conversion within districts will be developed. New technical and commercial activities will be necessary.

4. **Horizontal technological aspects**, where current bottlenecks, irrespective of the application area (new, existing buildings or districts), consist in the lack of cost-effective technical solutions for demand reduction, optimal use of renewable energy, accurate simulation tools to evaluate the expected impact of new systems and solutions in the energy use in buildings. We are aware of the lack of reliable measurements from Energy Management Systems that cannot adapt to user behaviour, or are not intuitive for the end-user. We anticipate underpinning R&D to support efficient labelling systems and standards with a sound scientific and technical basis, addressing current bottlenecks (i.e. when different standards or their different use leads to non-comparable results). Opportunities also exist to activate and optimise the thermal mass of building materials and develop new materials with low embedded energy, components and systems to maximise the usage of local renewable energy sources (e.g. through seasonal storage). We will require simulation tools based on interoperability principles and on new algorithms taking into account ancillary phenomena for a high accuracy in building physical predictions. They will increase the time-to-market criteria, together with the fast implementation and performance feedback. Simulation tools could find application in the area of new building construction (e.g. optimisation of building construction practices and optimised building system operation in a time/cost efficient manner through simulations) and in the area of existing building renovation (e.g. optimisation of the choice or renovation materials or specification of optimal operation improvements of existing HVAC systems). Opportunities also exist to develop robust wireless sensors and actuators that can make energy management systems cost-effective and widespread. The development of new standard protocols will make possible to analyse energy behaviour consistently all over the EU countries. Dealing with electricity the balance between demand and supply has to be satisfied at any time. Demand response solutions taking into account the user's feedback regarding electricity will be a crucial issue for both energy efficiency and peak load management. All these horizontal actions will ensure a drastic reduction of CO_2 during the building's life.

5. **Horizontal organisational aspects**, where current bottlenecks exist in the individual behaviour and social and economic development that have a strong effect on energy demand in buildings. Moreover, the introduction of new products and technologies in the construction sector is very slow (technological inertia), due to lack of information under real conditions of the performance of these products in buildings. Standardisation is strongly focusing on performance. Nevertheless, opportunities exist to adapt products, systems and technologies to the final user's need (comfort, quality of life, etc.) with the aim to achieve better energy efficiency in buildings and to ensure the expected reduction in energy use. Finally, new standardisation methodologies as well as new models of buildings need to cope with the real performance of buildings.

Each of the Research Areas has been further analysed and broken down into specific challenges. As many challenges overlap across the three application areas (Existing Buildings, New Buildings and Districts/Communities) and their presentation would have resulted in multiple similar descriptions, the following VENN diagram (Figure 5) has been prepared.

Figure 5 - VENN diagram showing inter-relationship among research challenges

REFURBISHMENT TO TRANSFORM EXISTING BUILDINGS INTO ENERGY-EFFICIENT BUILDINGS

- Systems and Equipment for energy use for existing buildings
- Envelope (for existing buildings)
- Solutions for Cultural Heritage (including diagnostics)
- Systemic Approach for existing buildings

CROSS-CUTTING CHALLENGES

HORIZONTAL ORGANIZATIONAL ASPECTS

- Relationship between User and Energy
- Geoclustering
- Value Chain and SMEs focus
- Knowledge transfer
- Business models, organizational and financial models (including ESCOs)

HORIZONTAL TECHNOLOGICAL ASPECTS

- Systems and Equipment for energy use (horizontal)
- Storage of energy
- Quality indoor environment
- Design – integration of new solutions
- Envelope and components
- Industrialization and mass customization
- Automation and control
- Life cycle analysis (LCA)
- Energy Management Systems
- Labeling and standardization
- Materials: embodied energy and multi-functionality
- Diagnosis and predictive maintenance (continuous commissioning)
- Systems and Equipment for energy production (horizontal)
- Diagnosis

NEUTRAL/ENERGY POSITIVE NEW BUILDINGS

- Systems and equipment for energy use for new buildings
- Systemic approach for new buildings

ENERGY EFFICIENT DISTRICT/COMMUNITIES

- Interaction (integration) between buildings, grid, heat network …
- Systems and Equipment for energy production (district)
- District and urban design
- Systems and Equipment for energy use (district)
- Storage of energy (district): thermal, electrical or other
- Retrofitting (district)

The diagram highlights those **"cross-cutting challenges"** which are relevant for more than one of the application areas, showing inter-relationships and common areas of research. This is the case for instance of **"Energy Storage"**, which is identified as a "cross-cutting challenge" as well as a specific challenge for Districts/Communities, or **"Systems and Equipment for Energy Use"**, which is identified as a "cross-cutting challenge" as well as a specific challenge for New and Existing Buildings. Although it is clear that some of the cross-cutting challenges build on different requirements and address different constraints, depending on the application area considered, the type of research required, including expertise and knowledge, is quite similar. We have therefore considered them in the following within the broader Horizontal Aspects, either Technological or Organisational (depending on their nature). Those challenges which have a similar heading but require different research approaches and solutions have been kept in their original position within each application area. Based on this logic, **each research challenge at the basis of the multi-annual Roadmap is described in the following sections in terms of "breakthroughs searched for"**.

3.2.1 Refurbishment to transform Existing Buildings into energy-efficient buildings

As far as "Refurbishment to transform existing buildings into energy efficient buildings" is concerned, four research challenges are described below:

> **Envelope**[19] **(for existing buildings):** breakthroughs are needed in the area of new materials, products and components to address energy efficiency with fault tolerant procedures and building techniques. There is a need to develop insulation systems specifically designed for the energy efficient retrofitting of existing and occupied buildings. "Long life" thin insulated panels with "High Performances" are missing; "adapted" products for external thermal insulation which keep the aesthetic aspect of the house and which are easy to install are not available at a low price on the market today. Multifunctionality, including energy production, distribution and storage technologies, shall be integrated into the envelope system for building retrofitting. Materials, products, components and building techniques used in new buildings need to be further developed and adapted to the constraints of existing buildings. For instance, the use of bricks and roof tiles must be taken into account in some countries when targeting the development of novel solutions for existing buildings. All this requires that energy efficiency is added to current retrofitting solutions.

> **Solutions for historic buildings and cultural heritage (including diagnostics):** there is a need for novel sustainable strategies, concepts, methodologies and techniques to improve the energy efficiency of cultural heritage buildings. This comes along with the need for accurate evaluation of the prerequisites and definition of different solutions for the control and maintenance of historical buildings. Innovative methodologies need to be developed to improve the planned maintenance and conservation policies at EU level, considering the adaptability to new building-usages and minimum intervention impact. Breakthroughs are searched for in new simulation tools for an open and dynamic geo-database accessible to all stakeholders to allow the definition of common EU standards and common approaches.

> **Systems and equipment for energy use (for existing buildings):** breakthroughs are needed in new methodologies to integrate comfort systems, energy management systems and local energy generation. New flexible and efficient equipment to be operated in existing buildings is needed, fully exploiting the potential of renewable energy sources, including PV. Specific efforts should be devoted to space heating and hot domestic water, representing the largest part of energy use in the buildings today. Heat pump technology has high potential but still needs further development to target higher performances, having as goals low cost,

19. A building envelope is the separation between the interior and the exterior environments of a building. The physical components of the envelope include the foundation, roof, walls, doors and windows. The dimensions, performance and compatibility of materials, fabrication process and details, their connections and interactions are the main factors that determine the energy efficiency and durability of the building enclosure system.

small size and suitability for retrofitting buildings. The residential sector is firstly concerned. There is a need to design reliable, scalable and cost-effective solutions for solar hot water and electricity production in buildings (e.g. multi housing or social housing stock). Energy efficiency enhancement is sought by applying new concepts of heating and/or cooling sources. This refers to higher efficiency as well as connection to existing thermal distribution systems. Passive systems need to be developed that will enable replacement of conventional ventilation and cooling systems, used both in office and residential buildings. Solid State Lighting (SSL) requires large demonstration to bring its full potential for energy efficiency into practice.

> Systemic approach (for existing buildings): integral concepts consisting of building and system technologies making up energy efficient refurbishment packages (e.g. 80% reduction in primary energy demand in the long term) are searched for, with improved comfort and quality of the indoor environment, as well as high reproduction potential, making optimal use of local energy opportunities and boundary conditions. Optimizing the refurbishment of existing buildings should integrate various technological solutions (envelope, systems, renewable energy sources, thermal storage …) which will interact with each other and with the existing building elements. This optimization process needs to follow a systemic approach; otherwise unexpected effects may appear on the whole system (for example degrading acoustic or ventilation performances when increasing envelope insulation). In this framework, energy efficient "kits" may emerge as an opportunity to retrofit buildings at affordable prices. Furthermore, research should address issues like how targets for improving the carbon performance of a building during a refurbishment are set and monitored, and how risk is allocated between client and contractor, while ensuring the quality of installation and commissioning.

3.2.2 Neutral/Energy-positive new buildings

As far as "Neutral/Energy-positive new buildings" is concerned, two research challenges are described below:

> **Systems and equipment for energy use (for new buildings):** in line with the need in existing buildings, energy efficient technologies need further development to target higher efficiency heating solutions for new buildings. Energy efficiency enhancement by applying new concepts of heating and/or cooling sources related, for instance, to renewables, heat pump and thermal storage is sought. Development of passive systems is needed that will enable replacement of conventional ventilation and cooling systems, used both in office and residential buildings. For new buildings these needs have to be combined with new design and technologies to provide higher heat transfer efficiency. The application of new materials has to be investigated as well as new designs able to provide larger and more efficient heat transfer areas. Finally, demand response solutions taking into account the user's feedback will be a crucial issue for both energy efficiency and peak load management.