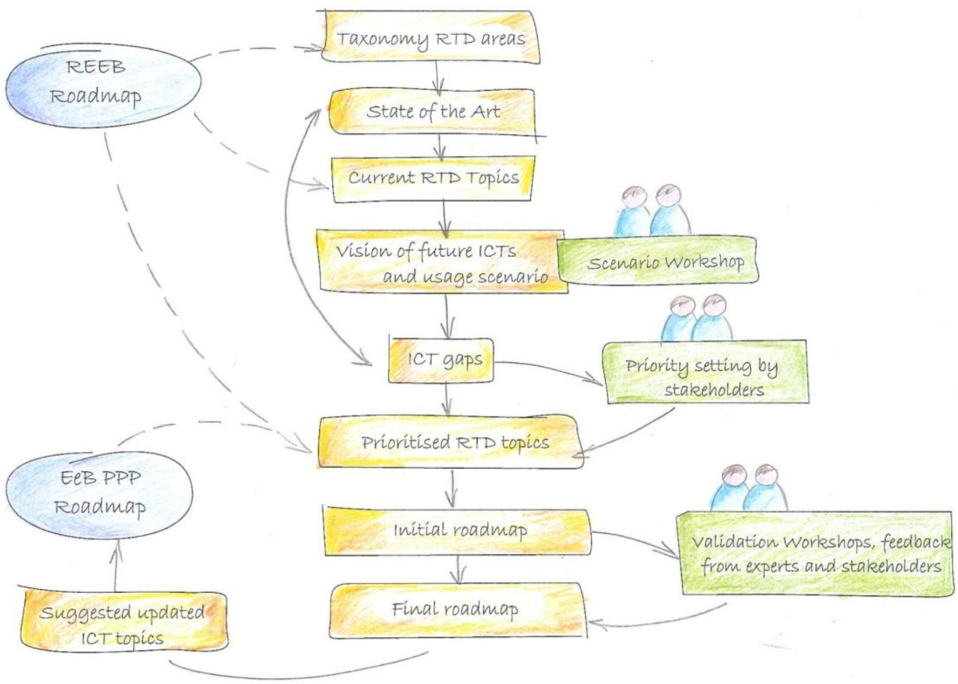
ICT Roadmap for Energy-Efficient Buildings Research and Actions



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ICT4E2B Forum

SEVENTH FRAMEWORK PROGRAMME

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ICT Roadmap for Energy-Efficient Buildings
Research and Actions

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2. Forewords

'New ICTs should give users more choices towards a more sustainable society'

The purpose of this roadmap is to clearly identify the research areas in the Information and Communication Technology (ICT) domain that will need investment in the years to come in order to achieve the target for building retrofit as well as new construction that contribute to sustainable development.

Making the necessary investments is difficult during an economic downturn, not least because there is no funding body that has enough resources to make a substantial impact alone. However, if the different stakeholders work together by focussing their efforts in the same areas, the necessary critical mass will be reached, innovation will become a reality and our economy will recover sustainably.

The question is who can define this direction. We are convinced that there is no guru or crystal ball. Buildings and construction expertise is not only in the minds of architects and engineers. This is an area that requires a multidisciplinary approach and through collective thinking by a range of experts, consensus can be reached about the right direction. Energy and city planners can contribute and the civil society needs to be involved as, in the end, we will all be working and living in these new buildings.

ICTs are already helping the sector to be more sustainable. Tools that assist in the design phase allow us to forecast the impact on environmental parameters of different design options before the building is constructed. Tools that assist in the operational phase make it possible to reduce energy consumption without compromising on comfort. Data analysis and visualisation tools aim to support a comprehensive decision-making process. And there are also tools to facilitate user engagement and participation. However, more research in ICTs for the building and construction sector is needed to ensure this trend will continue. New ICTs should not impose rigid constrains or controls but give users more choices and influence behavioural change towards a more sustainable society.

With these ideas and questions in mind the European Commission decided to invest a portion of its research and development funds in the ICT4E2B Forum. For two years the project has organised workshops and experts meetings around Europe to build consensus on the ICT research priorities for a more sustainable building and construction sector. The first drafts have been extensively discussed online by hundreds of experts. This book is the result of collective thinking that should guide our research investments in the years to come.

At the European Commission we pay careful attention to the identified research priorities as well as to the suggested actions to overcome non-technical barriers. We hope the book will also help National, Regional and Local authorities to create their action plans and research institutions, as well as R&D departments of private companies to align their innovation strategies with EU-wide efforts.

I wish you a useful and inspiring reading.

Mercè Griera i Fisa
Scientific Officer, European Commission
Communication Networks, Content and Technology Directorate-General
Smart Cities and Sustainability Unit

‘Stakeholder-oriented approach allows a shared and agreed vision of the future’

Worth at least 1.3 trillion Euros of yearly turnover (2010), the European building sector and its extended value chain (material and equipment manufacturers, construction and service companies) is on the critical path to decarbonise the European economy by 2050. It must enable reducing CO_2 emissions of buildings and districts by 90 per cent and energy consumption by as much as 50 per cent.

This is a unique opportunity for sustainable business growth provided that products (new or refurbished buildings) and related services are affordable and of durable quality, in line with several past or future European Directives. However, the sector is also directly affected by the ongoing financial and economic crisis (shrinking market, less purchasing power, but also potentially increasing building costs due to more stringent requirements to meet building energy performances).

The time frame left to develop innovative technology and business models in line with the 2050 ambitions is narrowing down to less than 10 years.

Energy Efficiency Building Association (E2BA) acknowledges the proposal of the European Commission to include research and innovation activities in the Horizon 2020 proposal, in continuation with the current Public-Private Partnership on Energy-efficient Buildings (PPP EeB). Its extension over 2014-2020 will both amplify and accelerate the collaborative research and innovation efforts implemented since 2009 at European level, in order to comply with energy demand reduction in buildings. It reinforces the value chain optimisation approach initiated in the PPP EeB which will require more dedicated R&D and innovation activities covering each of the components of the value chain and the whole integrated system.

It is well recognised that the Information and Communication Technology domain is a key factor to boost the development of innovative solutions in technologies and business models throughout the whole value chain, enabling wide adoption and deployment of standard-proof user-driven solutions throughout the European market (and beyond).

Within this context the scope of this roadmap is to clarify what the relevant research areas are within the ICT for Energy Efficient Building sector, defining a clear path and prioritisation among them. The added value of this roadmapping exercise is its stakeholder-oriented approach, which enables not only a clear technical path of what will be the evolution of the sector, but also a shared and agreed vision of the future, fully in line with the spirit of participation carried on by E2BA within the PPP EeB since its beginning.

It is therefore clear that from an E2BA perspective, the outputs of this roadmap are of pivotal importance, in order to fully integrate all the relevant ICT-based R&D activities into Horizon 2020 and the PPP EeB extension, with the aim of defining a common and comprehensive vision of what will be the future of Energy Efficiency in Europe, taking into account the ICT Industry as a key enabler to realise such a future.

I look forward to the completion and release of the roadmap.

Gaëtan Desruelles
Bouygues Construction
President of E2B Association

3. Introduction

In the field of energy efficiency, buildings are significant consumers of energy. Although numerous control solutions have been deployed already in many commercial buildings, these remain often standalone and proprietary legacy systems. The new sustainable challenges that buildings have to face today foster the development of new technologies and new solutions, which will drastically change our future built environment.

Within this framework Information and Communication technologies (ICT) are recognized as key for empowering people with smart solutions able to effectively reduce their energy and carbon footprint. But even if ICT is already demonstrating potential, it appears as a clear necessity to outline priorities in short, medium and long-term within the domain on ICT enabled energy efficient buildings, in order to fully leverage ICT solutions as a fundamental part of the smart building of tomorrow.

Within this book the reader will find a roadmap outlining the above-mentioned priorities, which enable the development of a clear vision of the future, together with all relevant technical steps to reach such a vision, and with suggestions on how to overcome non-technical barriers.

This roadmap is the main result of ICT4E2B Forum (www.ict4e2b.eu), a European-wide project able to bring together relevant stakeholders involved in the ICT and construction sector to investigate the role of ICT for Energy Efficiency in Buildings.

The roadmap development was based on intense cooperation with the stakeholders. By communicating with a network of experts, the research team gathered information about anticipated future state, gaps in the current state of the art, and prioritisation of the needs. Workshops in different locations around Europe were organised to ensure that this technology roadmap takes into account the needs from the different actors in the areas of construction and building.

The roadmap was developed through the following eight steps (Figure 3-1):

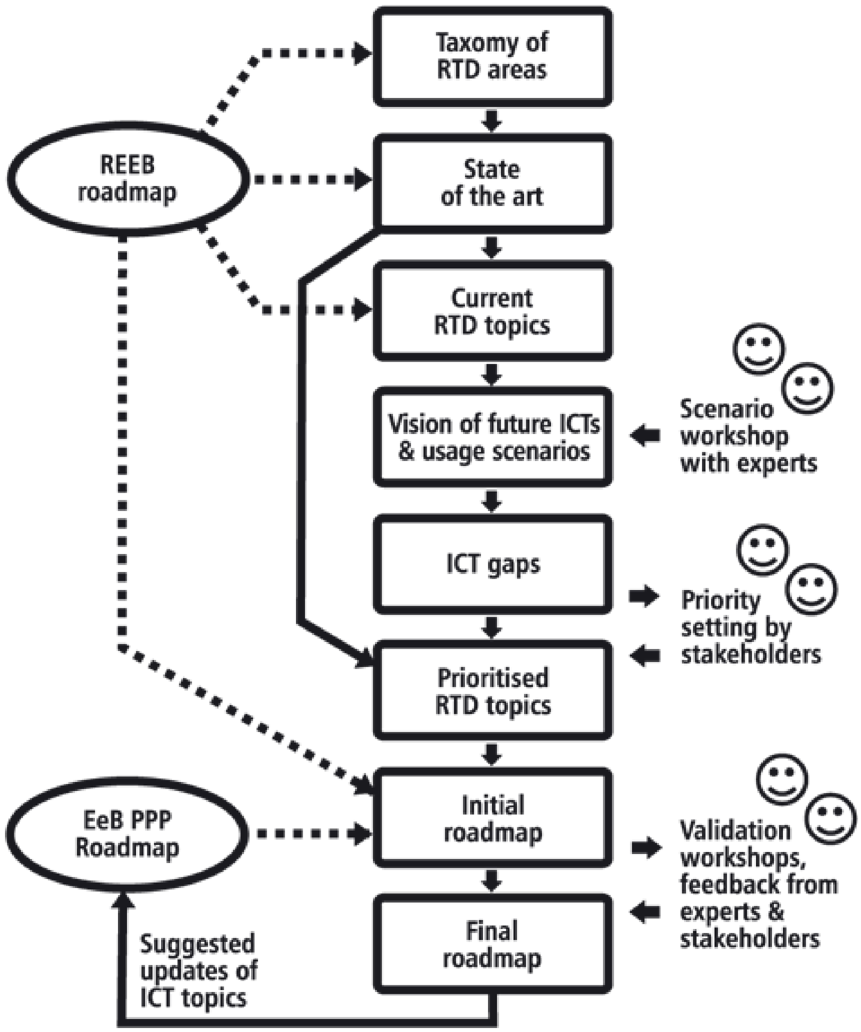

Figure 3-1: Scheme of roadmap methodological approach.

1. Taxonomy: Categorisation of research topics. The taxonomy is essentially unchanged from REEB project (REEB Project Consortium, *ICT Supported Energy Efficiency in Construction -- Strategic Research Roadmap and Implementation Recommendations*, 2010).
2. State of the art: Identification of ICT solutions that are already being used by the industry and main results from recently completed research.
3. Current RTD topics: Topics and main expected results of currently ongoing research. Up to about 100 European and national initiatives were analysed.
4. Vision of future ICTs and usage scenarios: Extrapolation of future ICTs beyond the state of the art based on current research, industry needs and ICT trends. Visionary scenarios how new ICTs could be used in 2020 and beyond. Several workshops were conducted in order to sketch scenarios about the usage of anticipated results from current and future RTD.
5. ICT gaps: Identification of required progress from the state of the art to the envisioned future ICT.
6. Prioritised RTD topics: The vision and gap analysis were presented to experts and stakeholders. They were asked to prioritise the topics at workshops and via polls, questionnaires and discussions on the web forum. The prioritisation was then analysed by thematic areas, and considered various stakeholder groups.
7. Initial roadmap: The initial roadmap was based on the REEB roadmap (Ref. 1). Prioritised RTD topics in short, medium and long-term were highlighted and further elaborated.
8. Final roadmap: The roadmap was finalised based on validation workshops with experts and feedback from stakeholders. Recommendations will be made to update the ICT-related topics of the E2B roadmap accordingly.

The discipline-specific priorities were mapped into a common view and vocabulary, thereby enabling communication and consensus building between experts in different disciplines that need to join forces to make fundamental improvements to achieve energy efficiency in buildings.

In the first project phase key knowledge areas and related application fields were identified. In addition state of the art in industry and related research and technology development (RTD) strategies were analysed and mapped based on the categorisation created in REEB project. The Strategic Research Agenda (SRA) consists of prior division of five distinct thematic areas, divided into three to four subcategories (Table 3-1).

Table 3-1: Identified five main categories and related subcategories.

Main category	Subcategory
Tools for EE design and production	• Design • Production management • Modelling • Performance estimation
Intelligent control	• Automation & control • Monitoring • Quality of service • Wireless sensor networks
User awareness & decision support	• Performance management • Visualisation of energy use • Behavioural change
Energy management & trading	• Building energy management • District energy management • Smart grids and the built environment
Integration technologies	• Process integration • System integration • Knowledge sharing • Interoperability & standards

In Chapter 4 interviews with relevant stakeholders are presented, representing the inputs collected during the roadmap activities. In Chapter 5 a shared vision of the future of ICT enabled energy efficient buildings will be shown, structured against the categorisation above. Chapter 6 defines the current state of the art at scientific and industrial level, detailing relevant R&D activities at European level and worldwide. In Chapter 7 the comprehensive results of this analysis are presented as a structured roadmap. For each area the following items were defined in the roadmap: state of the art, key research topics in short, medium and long-term, vision, drivers, barriers and impact.

4. Interviews with stakeholders

The ICT4E2B Forum project aims to encourage a closer dialogue and a more active cooperation between researchers, end-users, practitioners, building owners, technology suppliers, and software developers. A significant group of various stakeholders was involved in the validation of the priorities addressed in the roadmap presented in this document. Their views and knowledge are interwoven in the final vision. Two stakeholders representing different sectors, Construction and Automation, expressed their interest to elaborate on specific industry needs from a practical point of view. Not only do they explain where they see priorities for impact in the long-term, they also clarify how a roadmap on ICT for Energy Efficiency in Buildings at European level will help their sector to improve both the decision-making process and the execution of measures during the usage phase of buildings.

4.1. Sector: Construction

"'European regulation, just as regulation at national level, should carefully consider accountability for the functionality of what is being built. This happens in other industries, why not in buildings and the built environment?"

Ger Maas from Royal BAM Group, the Netherlands, is involved in European projects on the subject of E2B and Smart Cities. According to him, an energy efficiency roadmap becomes even more valuable at district level. "One of the biggest challenges for the construction sector is the management of the transition from centralised to decentralised energy generation", he says. "How can we properly measure and manage the energy flow in the opposite direction? How can we ensure guarantees that households will actually deliver the energy they generate, and will this be sufficient to provide the bigger players such as the industries and shopping malls with the amount of energy they need? In general, we need to better understand how reliable the decentralised energy system is and how we can carefully monitor this."

Will decentralised energy really take off? Important regulation and accounting are required, in which ICT can play a crucial role. Contractual practices are one of the main topics addressed in the ICT4E2B Forum roadmap, especially in the thematic area of EE Design and Production Management. Where [stimulation through] contracts in the construction industry are concerned, Maas stresses the importance of new business models with performance-based contracts instead of materials- and activity-based contracts. “Performance-based contracts have already been studied quite extensively”, he says. “We know how to handle them. There are already many public-private partner contracts in Europe involving 30 year finance, maintenance and management guarantees in operation. However, owners and customers are still hesitant to discuss this explicitly. Where I do see a gap, is in the proper use of these performance-based contracts on a broad scale, especially within the existing legal frameworks. European regulation, just as regulation at national level, should carefully consider accountability for the functionality of what is being built. This happens in other industries, such as the food sector, why not in buildings and the built environment?”

Maas expects that performance agreements will not only ease the integration of tools and communication between stakeholders; they will improve the quality of the discussions and the contracts and finally the performance of the houses, buildings and the whole built environment.

“We should adapt learnings from ICT and energy efficiency to parallel developments in water efficiency and the ageing society”

The added value of ICT in this change of direction, according to Maas, is the ability to monitor the quality of the buildings during their usage phase. This output allows partners to learn together for a sustainable future, based on real data and real measures. This does not only include monitoring through sensors. Even more important will be the analysis of specific – mature – data-reflecting the agreements in the contracts in place.

Considering the long-term vision of this roadmap, Maas stresses the need to look beyond the area of energy efficiency at the adaptation of ICT learnings to parallel developments in water efficiency, and even the ageing society. “These challenges require similar answers and our sector will have to deal with solutions in each of the areas”, he says. “Monitoring, for example, will be a major issue in retirement homes. How do people move inside the buildings and what does this teach us for improvement in design and construction?

The sensors and devices may look different, but the analogies behind the technologies are similar. Data and analysis obtained for energy efficiency could be equally used for other societal challenges. The relevance of these technologies stretches far beyond energy efficiency."

4.2. **Sector: Automation**

"There is a huge need for communication standardisation. We know what to do, but we don't know how to do it"

A roadmap on ICT for Energy Efficiency is not simply about technology and innovation, according to Olivier Cottet from the division Strategy & Innovation at Schneider Electric. "For us, this roadmap can function as a way to answer specific needs expressed before". He emphasises the need to extend previous research on the subject of energy efficiency in buildings to get to the next level of detail, and to better understand *how* to do things.

Cottet: "When we speak of communication between sensors and controllers, inside and outside the building, there is a huge need for communication standardisation and protocols for the exchange of data between machines, using web services. We need such research. When we speak of energy management, for example, the rules exist, we know what to do and we know this for years. But we don't know how to do it and if we are able to do it. We have already done good work, but the road is longer."

Another example: we know ways to reduce energy consumption of a building through reducing the losses and reusing fatal energy losses. In a data centre, for example, this could be done by using a heat pump to capture the waste heat. But how to build, set and control a heat pump able to reuse the captured waste heat? Cottet: "Again, we know what to do, we don't know how. And research programmes aim to find answers from this point."

"We need standardisation on lexicon, not on protocols"

One of the main outcomes in the ICT4E2B roadmap in different thematic areas, is the urgent need for standardised protocols. However, taking into account the evolving situation of energy markets and thus the need for flexibility, there is a limit to the functionality of strict standards in the long run. Cottet acknowledges the importance of standardisation on semantics, not on protocols. "All standardisations are discussed on the level of physical layer of the technology and not on the language. While in communications, for example, not the way we communicate - by paper or by email- is the problem. In energy efficiency the challenge ahead lies in the lexicon we use, many words are multi interpretable. There is a huge need to create a common language, in terms of words and values, such as temperatures, but also in European regulation. Each country has different standards and rules to measure the energy performance. Also, current rules and standards about air quality, for example, have been written in a time in which it was not yet possible to measure the quality of the air. A lot of imposed regulation is now useless, in that way standardisation in Europe is a must. But one should never standardise technology solutions - the technical layers - or you will stop innovation."

Despite various objectives in different sectors, Cottet trusts that stakeholders in the whole building value chain can make this standardisation happen, as long as standards will not contradict with the interest or open protocol strategies in one of the sectors.

5. State of the art

Introduction

This chapter outlines the current state of the art of ICT solutions, the industrial needs (the market requirements) and the non-technological barriers that need to be addressed in each of the thematic areas as defined by REEB (Ref 1). Other stakeholders' requirements, such as those of city officials and scientists, were obtained through expert hearings and discussions and are embedded in the results addressed in this chapter.

Although there are already many advanced tools and methods available for different disciplines, they often have limited flexibility or lack system integration and/or interoperability between different vendors. Many tools are expensive, laborious to use and require special expertise. Concepts for energy efficiency are often still missing. From a non-technical point of view, we see that many stakeholders take part in the building life cycle, including SMEs or even micro-SMEs, thus there is a missing role dedicated to the holistic management of inclusive processes. There are, therefore, still many barriers to overcome to optimise energy efficiency in buildings.

The second part of this chapter outlines the National RTD frameworks focusing on ICT for Energy Efficiency in Buildings, an analysis carried out in all the 27 countries of the European Union and some non-EU countries. This classification clearly reflects the relevance of REEB (Ref. 1), considering that many of the national programmes cover most of the five thematic areas as identified in REEB (Ref. 1): Tools for EE design and production management, Intelligent Control, Integration technologies, User awareness and decision support and Energy management and trading.

It is relevant to emphasise that Member States place considerable importance on the area of 'User awareness and decision support', an area which is normally not fully covered by research frameworks. The lack of standardisation in the energy, construction and ICT sectors appeared to be an open issue in all the five thematic areas.

This chapter also presents the relevant information from recently closed and ongoing projects within FP7 programmes (ENERGY, ENV, ICT, NPM, SME) and CIP programmes (ICT-PSP and IEE) on the topic of the impact of ICT for Energy Efficiency in Buildings.

5.1. *EE design and production management*

5.1.1. **Review of the state of the art**

An overview of the state of the art on EE design and production management is reported in Table 5-2.

Table 5-2: Overview of the state of the art on EE design and production management.

Design	Discipline-oriented analysis & dimensioning tools. General purpose CAD with discipline oriented add-ons.
Production management	Tools for contract & supply chain management, procurement, logistics, on/off site production management.
Integrated engineering	File exchange, email, web-based document management systems, collaboration support.
Modelling	Mostly document oriented tools. Model based tools are emerging (e.g. BIM-CAD).
Performance estimation	Numerous distinct tools for cost estimation, life cycle assessment and simulation.

Design

Design tools: There are a variety of applications for the design of buildings, technical equipment and urban plans. In this document we address only the generic aspects of these tools without going into specific details of each application. The methods and tools are mainly developed in parallel and independently. Many tools are made in-house by user companies or are provided by SME developers, often on national basis. General purpose CAD tools are provided by major software companies. Most tools address mainly detailed design, while only few support other design phases.

Although advanced tools and methods are available for each discipline, they are mainly stand-alone, designed for experts, with limited flexibility and lacking interoperability concerning models and design cultures. Special purpose tools need to be used for energy related issues as these are not covered by mainstream tools.

Integration: Most tools are turnkey with limited data interfaces concerning energy aspects. The basic problem is that a common model and interoperability methods are missing. A horizontal integrated information chain is not real and many error prone and time-consuming information handover procedures are still needed. Information sharing runs mainly via web-based document/file management systems. Mature collaboration and concurrent engineering tools for the one-of-a-kind buildings are missing. Vertically integrated life cycle design is still missing due to the lack of sufficient powerful data models, inadequate interoperability and fragmented design cultures across various disciplines.

Theory: The interaction of climate, building construction and occupancy, in relation to heating, ventilation and air conditioning is very complex and not yet fully understood. A detailed exploration of the complex physics involved requires analysis of the effects of design decisions on energy consumption, comfort, equipment and enclosure durability of buildings.

Production management

It is considered that today about 10 per cent of all global CO_2 emissions comes from the production of building materials. In particular steel, concrete/cement, bricks and glass require very high temperatures that can only be reached by burning fossil fuels. Construction activities account for about 5 per cent of energy used, including construction related transport. Construction and demolition waste accounts for about 22 per cent of all waste. Therefore for design a large variety of software tools is used for process and production management in construction. These tools are also used to evaluate CO_2 emissions, but many tools are developed in-house or by SMEs. Often these are for national markets due to local regulations and contractual practices. Thus only a few tools are from major international software companies e.g. scheduling and resource planning. This issue causes the existence of many different formats that are usually not compliant with each other. The main aspects addressed in production management are related to timing, costs and contracts. Energy efficiency, and sustainability in general, is an emerging concern.

Integrated engineering

The current integration of processes is mainly based on digital files that are shared by the different stakeholders that take part in the definition, realisation and use of the building. At the same time, workflows are manually managed, email being the main tool to support the interaction between the stakeholders. Although more advanced tools exist and in some cases they are being successfully used in other industrial sectors as automotive or aeronautics, these tools have not been adopted by the construction sector because they need many modifications and licensing conditions are not suitable for one-off projects involving multiple organisations.

Although the interaction between the stakeholders is mainly supported by digital systems, it is very common that the final version of the documents (contracts, plans, etc.) is requested in paper version, as a mechanism to avoid interoperability and compatibility problems and to satisfy legal requirements.

Addressing the following needs will take the current state of the art to the next level:

Standards: Definition of a common Building Information Modelling (BIM) for energy efficiency in buildings is needed. This will integrate the building design and bridge the gap with building operation tools. This extended BIM should be complemented with standardisation of building components catalogues, in such a way that any building component can be automatically searched and integrated in the BIM.

Community forums: These instruments support people in sharing both good and bad experiences with different energy efficiency solutions and practices. They could also serve as incubators for new ideas.

Catalogues: Intelligent digital catalogues of building materials, products, and services are needed. They should contain substantial product/service information (much more than simple geometry) in parametric format. They could, for example, contain configurable design solutions with embedded design logic. Domain knowledge is available in reusable form from catalogues including, for instance, energy efficiency related attributes. Examples: best practices, materials, products and components, suppliers, guidelines.

Modelling

Building Information Modelling (BIM): has become the key technology for representing data about products within the Architecture, Engineering and Construction (AEC) and Facilities Management (FM) industries for design, energy simulations and performance estimation. It is also used in building automation and control. Ideally BIM consolidates available product data from different sources to provide high quality and up-to-date information about buildings. Thus it has the potential to act as a single point of information that can be used by various applications avoiding time consuming, error-prone and costly re-entering of data. The current use of BIM is mainly for file based data exchange while data sharing using model servers in under early development. The existing data models still do not incorporate most concepts needed for energy efficiency analyses. Due to the limited scope of existing models and lack of supporting tools, expertise on BIM and laborious efforts are often needed to achieve interoperability.

Data validation: Whereas the benefits of BIM-based energy analysis have been demonstrated in several research projects, there are still problems related to data quality and maturity. Methods for data validation are needed. Using BIM data for energy calculations still requires a lot of manual work. This becomes critical in particular if several iterations are needed for energy optimisation purposes.

Performance estimation

ICT tools for performance estimation consist of numerous distinct tools targeting cost estimation, life cycle assessment, simulation of energy use and indoor conditions, and visualisation of these analyses for decision support. These tools are mostly based on local standards and simple static methods, leading to just basic approximation. Many tools are expensive, laborious to use and require special expertise. The estimation results can vary essentially depending on the used tools. This reduces their reliability and use as conformance criteria in contracts and regulations. The consequence is over- or under-dimensioned building service equipment i.e. increased whole life energy cost or excessive initial investment cost.

Poor integration of BIM-CAD tools, insufficient interoperability between all tools forming the chain of performance estimation, and the lack of appropriate data flows transporting the required semantic information, lead to a situation where the likely future performance of the building under design is hard to evaluate, especially in the early planning and design phases.

Gaps in current practices exist not only due to technological barriers such as insufficient ICT means. Available tools are often not used due to a lack of incentives to make additional efforts and to adopt enhanced responsibilities. It is also necessary to adjust the contractual conditions between the involved stakeholders, in this context especially designers and the client.

5.1.2. **Industrial needs**

Design

<u>EE enhancements:</u> Existing design and CAD tools should be enhanced concerning energy related data models and information.

<u>Applications for early design stage</u> of buildings must be made available. They should combine a concise building model description and modelling & simulation capabilities as basis for decision-making, considering building energy performance and the quality of indoor environment. Simple tools are needed for users who are not necessarily energy experts and only need preliminary guidance on feasible options.

<u>Interoperable interfaces:</u> Improved interoperability to support optimal energy efficient design of a building in architectural and energy engineering

design is required. A selection of the basic principles of energy mix and the basic energy systems, design of the energy distribution system and components and specifying the technical details are needed. Model consistency checkers, e.g. as web services, are needed to validate interoperability.

Guidelines for integrated design are needed to encourage the use of available new technologies and adoption of new ways of working.

Production management

Material and product tracking systems: Adoption of unique identification of products and systems to track their life cycle. Linking information about installed products with specifications in the BIM.

Catalogues of materials, products, suppliers: E-catalogues need to be enhanced with energy aspects: embedded energy in materials and products, energy requirements of production methods, operation and maintenance, energy-related qualifications of manufacturers and suppliers etc.

Integrated engineering

In the short term RTD priorities will aim to improve the current file based workflows to allow information server based workflows. This will integrate multiple collaboration mechanisms, such as multimedia content sharing and live editing and comments annotation, in such a way that interactions between the stakeholders can be automatically archived and managed in a holistic way. The main research topics to achieve this goal are:

Adaptive user interfaces that adjust to the terminal, capabilities, access rights and current context of the user.

System security such as protection against threats and attacks, denial of service and intrusion detection, privacy of the members of the community, identity management and trust in service based systems.

Model management tools: Many stakeholders participate in building design, execution and operation of a building, but everyone has a specific role that defines what he is allowed to see and edit. Model management tools need to allow the interaction between this large and dynamic group of stakeholders during the building life cycle and support multimedia contents. Model management tools need to be based on open standards that guarantee their interoperability with other ICT tools.

Integration of synchronous and asynchronous collaboration tools: Although many collaboration tools exist (email, file servers, blogs, social networks, document sharing and life editing, etc.), there is no strong link between them. All these tools should be integrated in order to share the same configuration data and to easily track the evolution of the building.

Modelling

Take up of model-based methods: The industry should take up and learn from already available model-based tools. The roles, responsibilities and workflows need to be adjusted for optimal use of these tools.

Attribute extensions of BIM: The BIM, more precisely IFC, has to be extended, because it was originally developed for architectural design, meanwhile opened to other domains, like structural analysis, HVAC or Facility Management (FM). The existing BIM objects have to be enhanced with energy information. This can be done mainly by enhancing attributes with minimal introduction of new object definitions to the IFC schema.

Model tuning based on feedback from building operation: Continuous commissioning during building operation has a big influence on energy savings. It provides valuable feedback for adjusting the algorithms and models of the applied optimisation tools and BIM-based design.

Performance estimation

Energy estimation in early design stage: Best practice guidelines and ICT tools should be provided for energy related design, analysis and decision-making in early planning phases for new buildings or renovation of buildings. This will provide information to architects and clients who are usually not energy experts. For this purpose, both BIM-CAD and energy simulation applications have to be extended with appropriate data, interfaces and visualisation capabilities.

Models for reliable and comprehensive life cycle cost calculation should include investment, maintenance and energy aspects.

Metrics: Definition of building energy performance indicators and methods to assess them using available information from various ICT based systems is needed.

Validation & certification of SW tools: Standardised methodologies are needed to validate performance estimation tools. Monitored data from real buildings should be used to validate and improve performance estimation models and to fine-tune the underlying theory.

Virtual testing environment: Important impact on energy and emission reduction is through improvement of building components (products), processes (e.g. building operation processes) and services, because they can be applied to many buildings (new and the existing stock). As the testing and evaluation of all products and services may be quite complex and expensive, there is a need to test them virtually according to different application cases including building types, user and climatic scenarios before their realisation. A simulation-based Virtual Energy Lab may be done with little effort to provide input for new products, processes and services.

Simulation: New tools for building energy performance simulation need to be developed, as well as methods for interfacing between design tools and simulation models for whole buildings and building envelope parts.

5.1.3. **Non-technological barriers**

There are several non-technological barriers for exploitation of ICT in design and production management of energy efficient buildings. For instance, one can identify the lack of experts and labour for extensive EE renovation of the European building stock. Moreover, short-term nature of many projects in the building sector does not allow the adoption of long-term strategies. These two barriers are the main issues hampering the design process of energy efficient buildings. The causes that directly affect the development and use of ICT in design and production management can be identified as follows:

- Specialised ICT tools, extra efforts and special competences are needed for EE design, analysis & planning.
- Lack of interoperability: using many special tools and exchanging data between them requires extra efforts for EE considerations.
- Lack of knowledge about building life cycle costs and future energy prices.
- The fragmentation and 'project oriented approach' of the building sector and the complexity of dealing with existing buildings, as well as the fragmentation of the value chain in the construction sector. Many stakeholders take part in the building life cycle, many of them SMEs or even micro-SMEs, thus there is a missing role dedicated to the holistic management of the overall process.
- For existing buildings, significant effort is required to first retrieve all relevant information, and to compile and structure it in meaningful form to be used by new solutions.
- Lack of precision of the current simulation tools reduces their credibility and the interest of stakeholders in them.

5.2. *Intelligent control*

5.2.1. Review of the state of the art

The field of building automation is not moving fast. However, one can identify some trends as shown in Table 5-3.

Table 5-3: Overview of the state of the art on Intelligent control.

Automation & control	Existing automation and control algorithms are most often restricted to sub-systems (heating, light, ventilation, micro generation), independent from each other, and hard-coded in the devices with little possibility to update or modify them by a centralized control instance.
Monitoring	Existing smart meters enable real-time electricity consumption reporting and visualization as well as bidirectional communication with smart grids. All needed sensors, with the required sensitivity and accuracy, are not available at reasonable cost for a large scale deployment.
Quality of service	Some self-diagnosis systems exist in the HVAC and lighting domains. Some sensors can also monitor their own functioning, and communication protocols also include error detection in the data frame. For communication protocols, many open or proprietary de facto standards co-exist with different properties.
Wireless sensor networks	Some 'Plug & Play' sensors already exist, whose features can be automatically taken into account by e.g. WSN-based BMS to optimise control of the related actuators.

Automation & control

EN 15232 is the standard concerning the energy impact of building automation, controls and building management. It provides a good overview of common off the shelf control functionality in a Building Management System (BMS). This is also reflected in common building control products (Ref. 2 and Ref. 3). These references describe Building Management Systems (BMS) and the functionalities they support, such as:

- **Schedules**
  An occupancy schedule can dictate when heating or cooling should be applied to meet comfort requirements.
- **Closed loop control**
  Low level control such as temperature control for one room or pressure control for a ventilation air-duct.
- **Occupancy based control**
  The use of presence detectors to control light and indoor climate.
- **Optimal start**
  A technique to decide when to start heating or cooling before occupancy start. Starting too early would mean energy losses, starting too late discomfort.

A common issue is that the following functionalities are in general independent for each building dimension:

- Heating, cooling and ventilation
- Lighting control
- Blind control
- Access control
- Security
- Power distribution
- μ-generation and corresponding storage systems

Energy reductions are possible through, for example, combining heating, lighting and blind-control, interventions that are not commonly exploited. Although it is still far from being common, some emerging applications of model predictive control are applied to buildings. In this case a conventional BMS manages the building, but at the basis of this system is optimising software that operates the BMS, e.g. changing the temperature set point within a comfort interval. This operation is performed taking into account information such as e.g. weather forecast, real-time energy pricing and with this data it makes an optimal trade-off between energy consumption, comfort and economy.

In the last year there was an increase in activities around high-level energy management such as model predictive control and building control based on weather forecast.

Monitoring

Monitoring is a standard component in a modern BMS (Ref. 2 and Ref. 3). Measurements used for building control are also stored in trend logs and signals such as energy consumption and temperatures support information for user interfaces and automatically generated reports.

Over the last years several offers around 'building analytics' have emerged. The functionality of such analytics is energy benchmarking of buildings and detection of malfunction. Many are software-only solutions that are not necessarily running on premises.

Quality of service

Some basic self-diagnosis is commonly available in automation control products: for instance the controller may detect if the wire of the temperature sensor breaks and will be able to set up a procedure to fix the problem. When a building automation system is available, there is usually a large quantity of self-diagnosing functionality with associated alarms. An alarm can be issued if, for instance, the equipment is faulty or the temperature is out of range (Ref. 2 and Ref. 3). There are also more advanced services that attempt to identify failures based on historical building data. This service could, for example, identify causes of increases in energy consumption and other kinds of failures (Ref. 4).

Wireless sensor networks

There are a number of wireless technologies for building automation on the market. So far, none of them is interoperable between different vendors. However, there is significant standardisation ongoing, predominantly in the ZigBee Alliance (Ref. 5).

5.2.2. **Industrial needs**

Automation & control

The smart grid concept tries to balance the energy flow between the producers and consumers. Since buildings are the largest energy consumers it is important that they have the connectivity and functionality to interoperate with the smart grid.

On the contrary, with renewable sources there could be an oversupply of energy, thus decisions should be reached on how to exploit the amount of energy that is produced. The optimisation of the building behaviour should take into account this scenario to optimise the energy management of the building.

Monitoring

The first step to decrease energy consumption is to understand where the energy is being consumed. Instruments dedicated to monitoring and systems for efficient communication should be implemented with high resolution to allow stakeholders and users to increase their awareness of energy consumption. Adequate tools that can make this information better visible to the stakeholder have to be identified and widely applied.

Quality of service

The challenge is to improve the quality of service. That is, to detect the cause of a problem but also to adequately describe it. An equipment failure can often result in energy losses but even though it is detected by the system it may not get repaired unless the tenant complains about comfort. A typical alarm message could be ‘Alarm: Part1 is faulty’. It is recommended that this message is completed with information on the cost per month that this failure may cause. This message will raise greater attention from the tenants since it is more comprehensible and it is about money saving. This will require that the system has the capability to evaluate rough cost estimates.

Wireless sensor networks

Wireless communication for building control devices are considered as promising tools, but building specific standards have to be developed to ensure interoperability. In addition, protocols addressing sleeping devices have to be considered to ensure long lifetime of battery-less devices.

5.2.3. Non-technological barriers

The main issue highlighted in this chapter is that stakeholders should become aware of the economic benefits they could generate through increased energy efficiency. Cost is a very powerful psychological barrier. Moreover, the decision criteria for the stakeholders, even for commercial organisations, during the actual period of economic crisis are merely related to the initial investment and not to the return of the investment period. This gap could be bridged by increasing energy awareness, by developing simulation-based estimation of energy savings, and by the growing number of competitors in the market of energy service contracts. Finally, it is relevant to notice that in many cases the stakeholder who is responsible for the control system is not the one who pays the energy bill. For example, a building owner has no direct economic incentive to invest in intelligent control when the tenants are paying the energy bill. In particular, he has little incentive to verify that his building is performing well. In this context the need of cost decrease of BMS systems is another important issue that could be considered a barrier.

5.3. *User awareness and decision support*

5.3.1. **Review of state of the art**

The main role of ICT in User awareness and decision support is to inform the users of buildings about their current energy consumption, what they can do to decrease it and how their activities will influence energy use in short and long-term perspective. Information is the key issue in supporting decisions and creating awareness. Information should be easily available, comprehensible and useful for further operations. It is possible to gather information about many environmental factors (temperature, humidity, CO_2 concentration, solar radiations, etc.) and predict possible energy use.
An overview of the state of the art in Industry is given in Table 5-4.

Table 5-4: Overview of state of the art in industry for User awareness and decision support.

Personal control systems	Control level for individual users.
Energy labelling	Role of energy performance certificates in user awareness.
LCA Software	Use of Life Cycle Analysis Software to disseminate knowledge about building properties.
Economic feasibility	Need of cost decrease of BMS systems.
'Real-time' pricing	Use of smart meters in creating aware use of energy.
ICT tools in existing buildings	Possibilities of applying ICT solutions in existing or retrofitting buildings.

Personal control systems

In office buildings the central unit will control different devices in order to avoid an increase of energy use. However, in residential buildings the decision belongs to the user. To take a proper decision the users have to know - the more precisely, the better- how their activities will influence the energy use and how much money they can save or lose with this. Therefore most of the systems in residential buildings focus on the visualisation of energy use and simple control of some of the devices available for people. The ability to control the devices allows people to use them in the periods when power is cheaper and use only the necessary devices in the peak hours. This is possible with real-time electricity tariffs (also known as dynamic pricing).

Another tool is a demand response mechanism used to encourage consumers to reduce demand, thereby reducing the peak demand for electricity. In most cases demand response allows customers to curtail their consumption when the convenience of consuming that electricity is worth less to them than paying for the electricity. Demand response mechanisms are widely used, particularly for commercial energy customers, in United States, but is expected to be implemented more widely in Europe in coming years. The companies focused on this type of activity will have to agree with final consumers on formal and informal incentives regulating the maximum demand for electricity by the users. With many users the companies can manage peak demand and cooperate with electricity providers on preference prices.

The main drivers to increase the emphasis on the whole lifetime performance of buildings are summarized as follows:

- increasing user awareness
- increasing regulatory requirements
- shift towards performance based contracts

Energy labelling

As far as User awareness and decision support in the building lifecycle is concerned, building certificates (energy labelling) might be helpful. Certificates like LEED, BREEAM, Green Star or CASBEE take into account the majority of the lifecycle of the building and present it in a consistent way. Recent ideas on uniform standards and calculation methods resulted in projects such as 'Open House' (Ref. 6), which aims to develop and implement a common European transparent building assessment methodology. The methodology will be consistent with EPBD directive and can be used all over the Europe. Currently, Open House methodology is elaborated and evaluated on existing buildings in more than 50 case studies.

The classification in certificates aims to provide an easy-to-understand snapshot of the standard and quality of the building. The concept of certificates is easier to understand by people with non-technical backgrounds and it is more convenient to present to the general public, compared to situations in which people get a set of numbers regarding the building energy use. By using the classification in certificates, people are more aware of the advantages of novel techniques used to increase energy efficiency, and somehow they promote solutions among their family and friends.

LCA software

Following the certificate path, software can provide a full overview of the carbon footprint of the building in Life Cycle Analysis (LCA) programs (e.g. SimaPro, GaBi, Gemis). The usage phase of buildings is not the entire environmental story for buildings. LCA software can give more detailed calculations on the impact of the building in different scenarios, from the materials used to construction works and use and disassembly of the building. The scheme in Figure 5-2 presents the approach of LCA technique for the whole process, starting with planning, through construction and use to disposal. The energy and materials consumed in each process are taken into account.

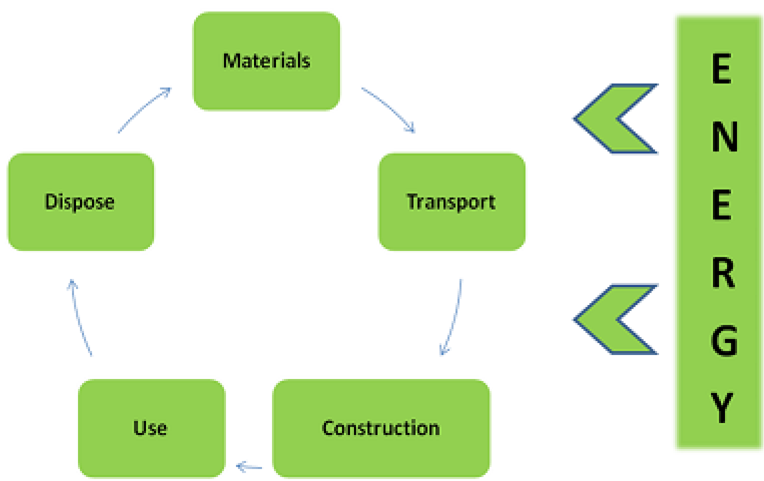

Figure 5-2: Scheme of Life Cycle Analysis approach.

The common unit used in LCA software is CO_2 emissions in the atmosphere.

5.3.2. **Industrial needs**

Economic feasibility

One of the most important technological needs for improvement of user awareness is to decrease cost of equipment used for the visualisation and control of energy use. Building Management Systems are still very expensive for the typical user and practically not available for residential energy customers. A proper and realistic ROI factor is very important for investors and users who have to understand how their behaviour influences energy use and what savings they can count on. In order to provide this information real-time energy costs and payback simulation must be implemented into the system and be presented easily to the user. It would be good to provide advice on how to influence and decrease energy use by simple solutions and actions that users can perform with small effort and almost instant results.

Another important issue is the intuitive interface to ease the operation of the equipment. Use of local language is a must, otherwise people will not be eager to learn and use the system.

Real-time pricing

Behavioural change will be stimulated by real-time pricing. So far, the business model of real-time pricing in the residential market is only used in a few regions, such as in California. It is more common in business models offered to bulk energy consumers in industry.

To support real-time pricing smart meters must be installed as a prerequisite. Additionally, it is essential that end-users are seamlessly provided with easy understandable overall consumption data, and that they can choose between different options how to adjust their current behaviour in real-time. Demand response mechanism comes alongside this solution and allows real savings for the customers.

Sub-metering and interoperable information exchange between sub-meters and major consumers (end-devices) is required. Currently, there is a lack of appropriate business models to stimulate information exchange about demand/supply profiles.

It is also essential that commonly agreed standards are developed to describe how to exchange energy-related information. There are few systems of communication developed by different institutions and organisations. One of these systems should be chosen as principal, in order to allow standardisation of the grids.

ICT tools in existing buildings

One of the technical issues is the implementation of BMS and ICT tools in existing buildings. Even though installation works can be easily performed while constructing buildings, it is difficult to implement systems in existing buildings. Retrofitting of buildings can be a good opportunity to install some of the BMS features. If the implementation of an active controlling system is not possible, at least measuring devices for visualisation of energy use are very helpful in creating user awareness. Systems with wireless communication and even self-powering might be an answer for existing buildings where installations works cannot be performed in full scale. The FP7 research project TIBUCON (Ref. 7), deals with the development and tests of a self-powered wireless sensor network for HVAC system energy improvements.

5.3.3. **Non-technological barriers**

One of the most important non-technological barriers in terms of user awareness is that people are usually not willing to change their behaviour and learn how to do new things. They have developed habits through the years and it is not easy to convince them to change. Therefore the presented solutions have to be user-friendly, relevant and effective. In this context the development of intuitive and easy-to-use interfaces is essential.

Another issue is the potential feeling that one is losing full control of the surrounding environment and that 'computers' cannot know what is good or not for people. Education and training of people should be answers to these doubts, proving that ICT systems are useful and do not affect the quality of living in the building in a negative way.

The lack of awareness also exists in universities where BMS and ICT solutions do not get enough attention during engineering courses. The teaching programme for architects and civil engineers should be updated to explain to students how ICT can easily improve energy efficiency in buildings and influence users behaviour.

Regulation is another area to be reviewed. Possible changes in regulations concerns technical designs and solutions for infrastructure network, as well as assuring proper energy efficiency (through different means, such as using ICT) and providing information to end-users (e.g. via smart meters).

5.4. *Energy management and trading*

5.4.1. **Review of state of the art**

Future smart cities are expected to be very large and complex ecosystems, where interactions among the various involved entities may lead to emergent behaviours (system of systems characteristic). Managing the energy footprint better is one of those challenging goals, and the smart grid in conjunction with energy efficient buildings may provide a key tool in achieving this.

Today, energy management is executed mostly at stand-alone mode. This means that, for instance, a smart building is trying to optimise its internal behaviour towards a better energy footprint, a smart house is trying to optimise the use of its devices, and a distribution system operator (DSO) is trying to predict and manage the energy on smart city neighbourhood level. However, all of these efforts are disconnected and he stakeholders in a smart city do not cooperate. In the best case some Demand Response (DR) mechanisms are in place.

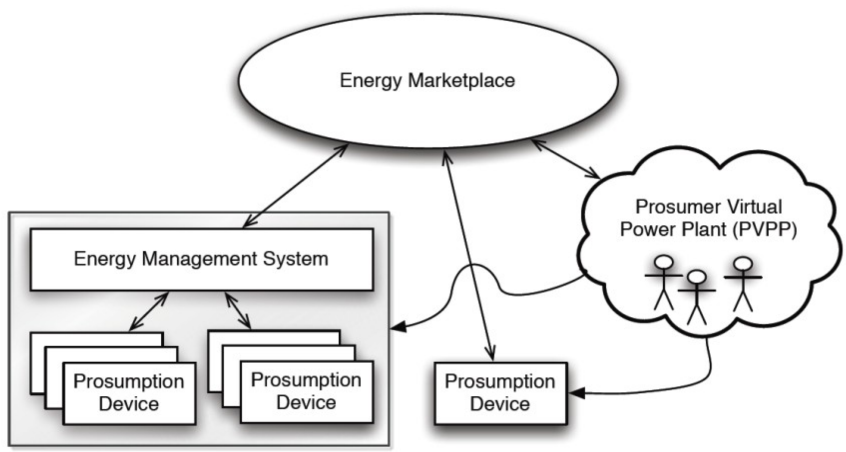

Figure 5-3: Future Energy Management and Trading.

In the future smart city context Demand Side Management (DSM) will be more challenging as the energy prosumers are expected to hold distributed energy production (e.g. PV panels) or presumption (e.g. electric cars) facilities. Those facilities, once aggregated and operated intelligently, may be treated as virtual power plants (VPP) whose resources are distributed within the city. The key lies on the emergence of such groups and the effective interaction with them. As depicted in Figure 5-3, energy management and trading will be more strongly connected with potential real-time interactions. Additionally, buildings are expected to be an integral part of VPPs and participate in internal and external energy management schemes by regulating their energy signature flexibility according to a multitude of objectives, including energy trading benefits. The optimal usage of local resources and the benefits they offer, e.g. negligible transmission costs due to physical proximity, may provide a promising element for the success of local stakeholder interactions e.g. via a local energy marketplace.

The following paragraph focuses on how energy management can be applied to procure, apply and potentially reuse energy in an economic, secure and sustainable manner. This requires an overview of the relevant stakeholders and their business needs, which shall be outlined as indicated in Figure 5-4 and Table 5-5.

Table 5-5: Relevant stakeholders for Energy management and trading.

Energy producer	A producer of energy may use renewable or non- renewable sources of energy to transform energy from one type to another. As such the producer may need to exploit or procure natural resources to operate his generation facility. When no resources are needed for the generation system (i.e. wind generation / photovoltaic / geothermal, etc.) the producer is confronted with other needs that specifically relate to the generation system.
Energy retailer	The role of the retailer is to purchase electricity on the wholesale market and resell the procured electricity on the retail market. The end-user is usually not capable to buy electricity on the wholesale markets, as such. There are various constraints to be active on a wholesale market and the transaction costs outweigh the value of possible advantages on the wholesale market. The complexity and volatility of a wholesale market can be better tackled by an entity which can reduce transaction costs with economies of scale, further applying a procurement strategy to deal with the risks that exist in wholesale markets.
Energy user	The role of the energy user is to procure and apply energy in his energy related applications. If the energy user has his own generation capacities installed, he may use this to supply energy for his own energy applications or to feed the energy into the grid. Various strategies exist to secure a sustainable, secure and economic usage of energy.
Demand side management operator	A market role that has evolved in various forms in recent years is the demand side management provider. In other cases this role is defined as a demand side manager (DSM), demand response (DR), contracting provider, etc. The individual business scenarios are very different in their individual approach. Overall the demand side management provider interacts very closely with the customer and evaluates the energy situation of the customer with the energy related applications. Once having understood the situation and potential future needs, the provider applies various technical and non-technical methods and systems to help the customer apply energy.

5.4.2. **Industrial needs**

For Energy management and trading the focus is on the following industrial needs, reflecting those identified by REEB (Ref. 1):

- Better interoperability and reliability of the technologies and systems
- Migration towards fully service-based infrastructures
- Adoption of collaboration tools for open cross-industry information exchange
- New technologies for real-time energy management
- Enhanced energy prediction models and tools
- Energy optimisation and control models and tools
- Real-time consolidated reporting and integration with business processes
- Intelligent energy-aware and adaptable devices/appliances etc.
- Models and methods for assessment and comparison of energy footprint during the whole lifecycle
- Tools for security, privacy and trust assessment
- Scalable integration with smart grids and smart cities
- Internet based energy services for smart buildings
- Easy integration with online energy market places
- Easy integration of alternative energy resources and demand-side management
- Tools for the assessment of approaches during their whole lifecycle including cost, environmental impact, maintenance etc.

5.4.3. **Non-technological barriers**

Energy management and trading faces some non-technological roadblocks. Privacy is a major issue, as detailed energy consumption measurements may reveal user activities within a building. There is a lack of understanding about the appropriate, measurable Key Performance Indicators for energy management and trading. Their interdependence with other goals of the enterprise is also not clear. For enterprises there are several barriers towards the adoption of energy efficient technologies. The three main areas identified are depicted in Figure 5-4. It is needed to understand how innovation can be achieved and what its impact is for the whole lifetime of the approach. Additionally, legal, financial, cultural and social barriers might need to be further investigated to assess the impact, as well as possible strategies to tackle their blockers.

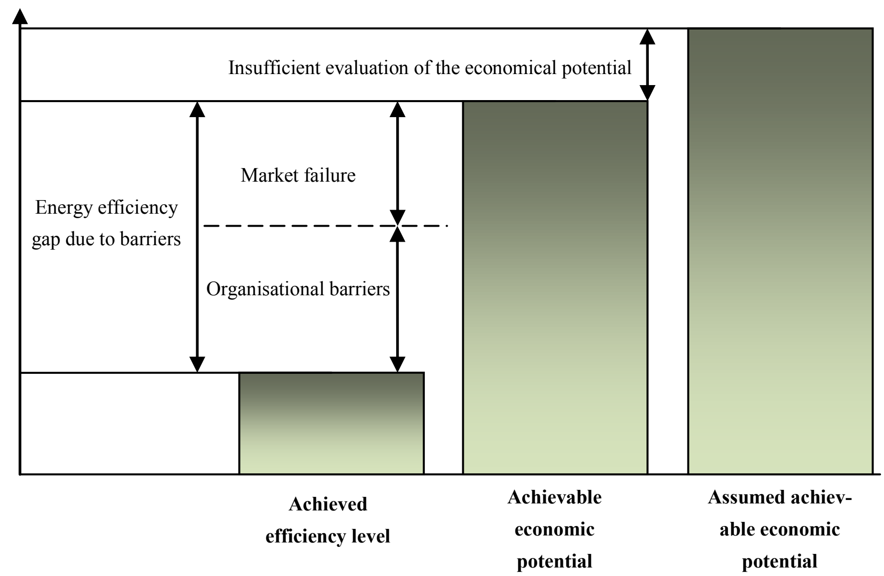

Figure 5-4: Energy efficiency in companies (Ref. 8).

Potential blockers include:

- Lack of awareness about innovation for energy management as part of an ecosystem;
- Failure to clearly demonstrate the benefits in real-world lighthouse projects;
- Lack of market availability and openness;
- Absence of policies and incentives at national and European level;
- Difficulty overcoming the established energy systems and providing migration solutions to next generation open collaborative energy management;
- Inadequate workforce skills and training;
- Lack of meaningful stakeholder participation.

5.5. *Integration technologies*

5.5.1. **Review of state of the art**

The importance of collaboration between different design disciplines has been widely recognised by the building industry. Traditionally this is achieved through physical meetings between the representatives of different design groups. However, this collaboration faces more challenges when dealing with large and complex design problems. Various approaches have been introduced to face this problem, such as multi-agent systems (MAS) and multi-disciplinary design optimisation (MDO). The former represents an advanced, ICT-based framework that facilitates collaborative design through communication, data and knowledge sharing and negotiation, while the latter represents a theoretical modelling approach which facilitates collaborative design through a thorough analysis of the technical problems.

To be effective, organisations need not only to negotiate their migration from a knowledge sharing (first generation) to a knowledge nurturing (second generation) culture, but also to create sustained organisational and societal values. The latter form the third generation of knowledge management and represents key challenges faced by modern organisations in the Architecture, Engineering and Construction (AEC) industry. This value creation is grounded in the appropriate combination of human networks, social capital, intellectual capital and technology assets, facilitated by a culture of change.

The modern vision considers the Building Automation (BA) domain and BMS as open systems for a full comprehensive building control network, designed on several types of bus systems, that:

- encompasses every building system,
- enable competitive bidding and allow best-in-breed product selection,
- have a dynamic application, able to utilise enterprise technologies and present new opportunities and added value for manufacturers, system integrators and owners alike.

The biggest challenge is in the market. There are many system technologies available that claim to be an open system technology: each one has its peculiarity and standards, but only few of them have gained wide acceptance and application. However, they have very different networks, software (communication protocol and configuration tools) and hardware requirements. For all practical intents, integration will solve the mutually exclusive solution approaches of co-existing different technologies, by relegating the sharing of information through a gateway.

To evaluate the best technology, experts suggests considering the following main goals:

- Open system: by implementing an end-to-end solution that is Open, Interoperable and Multi-Vendor. The device level of interoperability (and interchangeability) affects the network architecture and the ability to create multi-vendor solutions. Independent product distribution provides system integrators and owners the opportunity to select the best-in-breed products without being tied to a manufacturer specific solution.
- Market presence: to illustrate the influence each technology has on the market. It involves evaluating the user community activity and the extent of the installed base.
- Solution approach: which reveals the strengths and weaknesses of each technology solution. Common similarities of each are identified in the delivering of complete end-to-end solutions, with several own control devices and operator interface options. Focusing on differences, significant divergences are in device interoperability, network management, product distribution and integration of new technology.
- Product distribution: the integration of new technology is vital for commercial success and market influence.
- Network management: functions are used in every control solution to design, configure, commission and install devices. In proprietary solutions these functions are tied to a proprietary network database and are either distributed among several software applications or bundled with the operator interface application. Often network management functions appear invisible or operate automatically in the background during system/device configuration.

5.5.2. **Industrial needs**

Today, one of the main problems for the European industry is the presence of many different consortia and initiatives to certificate standards. This fragmented situation produces a big disparity of certification. This makes it also more difficult to select the most relevant standards that we have to compare performances in buildings for different regions in Europe.

The present fragmented approach in the market suggests that industry sees no business advantage in a harmonised approach, even if we conclude that the harmonisation of these different standards is needed.

A large variety of different products on the topic of energy management in buildings compete for a place in the market. This means that every software application is competent in just some parts, due to the complexity that involves the process of energy management in buildings. There is the need of a reference architecture that covers the main key points in this field to have a robust tool to operate this process.

With regard to systems integration, each company or vendor uses their own technology depending on their know-how or expertise. This situation produces a wide variety of different technologies coexisting, and the integration of all of them is difficult. As such, it is a necessity of the industry to develop a SOA based Integration Service Platform (ISP) and a definition of the gateway installed in each building.

5.5.3. **Non-technological barriers**

The main barrier to adopt new technological developments by the building sector is its fragmentation and project-oriented approach. A lot of stakeholders take part in the building life cycle, many of them SMEs or even micro-SMEs, and usually, no one leads the overall process. Also, the project-oriented approach of building sectors makes the adoption of long-term strategies very complex.

Another important barrier is the complexity of dealing with existing buildings: general lack of data, few existing data available only on paper, very simple and un-automated installations, etc.

From an economic point of view, the current static energy price implies long amortisation periods, which discourage investments in energy efficiency. However, it is expected that in the near future the energy price will be changing real-time and come closer to the real price.

5.6. *National RTD frameworks*

The European Union Member States are fully aware of the role ICT will play in the near future when analysing, designing, monitoring and operating buildings. They also recognise ICT as a key enabler for empowering people with both smart e-metering and new smart devices. However, it is not always clear to them how ICT will help, what the quantifiable impact are, or the most appropriate solutions. Increased investments in research on ICT for energy efficiency in this field have already been put in place at National level.

National RTD frameworks focusing on ICT for Energy Efficiency in Buildings have been analysed in all the 27 countries of the European Union. Many Member States do not have any National RTD framework in this specific sector. Some countries do run projects in this specific sector, but do not have a National RTD framework. In some countries a framework has not been identified. Therefore, during the comparative analysis, only 18 countries out of 27 have been assessed and are listed in Table 5-6. Figure 5-5 shows Europe's map of the National RTD frameworks assessed in this report.

Table 5-6: Analysed Member States.

European Union Member States			
Austria	Belgium	Denmark	Estonia
Finland	France	Germany	Greece
Hungary	Ireland	Italy	Netherlands
Poland	Portugal	Romania	Spain
Sweden	United Kingdom		

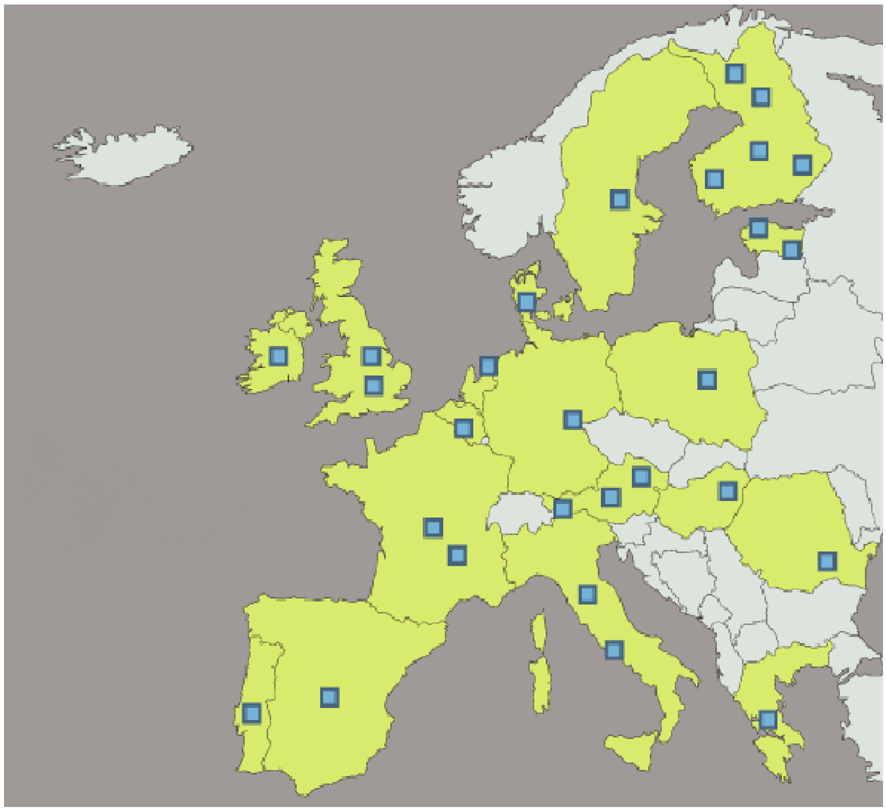

Figure 5-5: EU 27 map on National RTD frameworks on Energy Efficiency in Buildings.

5.6.1. **Methodology**

- The Qualitative National RTD framework analysis aims to identify and evaluate the non-covered five thematic areas (as defined by REEB Ref. 1) in each of the categories.
- The Quantitative analysis aims to identify the importance of National RTD frameworks by the following parameters:
  - National level RTD framework starting year,

– Distribution of National Research Programmes among the thematic areas.

Concerning the National level RTD framework starting year: three different years have been considered as a reference to better understand the willingness from the European Member States to invest in research programmes in ICT for Energy Efficiency in Buildings.

- Before Kyoto (before 2005)
- After Kyoto Protocol (from 2005 to 2008)
- After the 20/20/20 EU Strategy (after 2008)

The Kyoto Protocol, an international agreement linked to the United Nations Framework Convention on Climate Change, was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. Following the Kyoto Protocol, in which the European Union has long been a driving force, the EU adopted an integrated energy and climate change policy in December 2008. This includes ambitious targets for 2020, hoping to set Europe on the right track towards a sustainable future with a low-carbon and an energy-efficient economy by:

- cutting greenhouse gases by 20 per cent (30 per cent if international agreement is reached),
- reducing energy consumption by 20 per cent through increased energy efficiency,
- meeting 20 per cent of our energy needs from renewable sources.

The starting year will show how many Member States started their RTD activities in the ICT sector before any binding commitment for reducing greenhouse gas emissions, how many RTD programmes were introduced after the Kyoto Protocol entered into force, and in particular the commitment to reduce greenhouse gas emission to an average of five per cent against 1990 levels over the five year period 2008–2012. It will also show how many countries developed RTD activities in the ICT field in line with the integrated energy and climate change policy of the European Union.

The analysis identifies which of those thematic areas (identified in REEB, Ref. 1) are the most widely covered by the research activities on ICT for Energy Efficiency in Buildings at National level. The analysis will further illustrate how different Member States are investing in RTD research activities and on which areas they focus most.

5.6.2. **The thematic areas covered by the National level RTD Programmes**

The 5 thematic areas covered by the National level RTD Programmes within the domain of ICT for Energy Efficiency in Buildings are:

- Tools for EE design and production management
- Intelligent control
- User awareness and decision support
- Energy management and trading
- Integration technologies

These are the areas previously defined by REEB (Ref. 1) and used in further classifications.

5.6.3. **Ranking of the thematic areas covered at European level**

The ranking of the thematic areas at European level is shown in Figure 5-6.

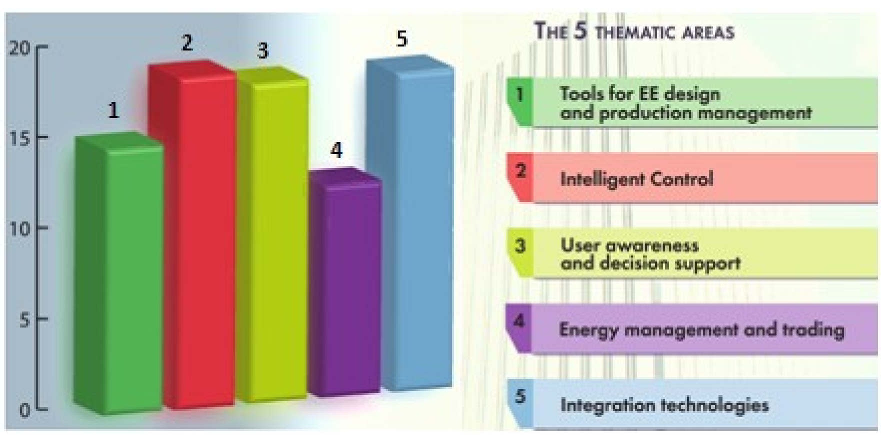

Figure 5-6: Ranking of thematic areas covered at European level.

The most covered area is 'Intelligent Control' (19 National level RTD Programmes), consistent with findings of the REEB project (Ref. 1). 'Integration technologies' and 'User awareness and decision support' have each a coverage of 18 National level RTD Programmes, followed by 'Tools for EE design and production management' (16 National level RTD Programmes) and 'Energy management and trading' (12 National level RTD Programmes).

This classification work clearly reflects the actuality of REEB (Ref. 1), with respect to ongoing RTD activities at National level, considering that many of the programmes cover most of the terms of the REEB classification (Ref 1).

Additionally it is important to emphasise that Member States give considerable importance to the area of 'User awareness and decision support'. This area is normally not fully covered by research frameworks, as it is not seen as a priority one. 'Energy management and trading' is the least covered area. In general, energy management innovation is carried out by energy suppliers, utilities and service providers such as ESCOs. Energy trading research and innovation for financial energy trading, rather than physical trading, is carried out by traders, energy marketers and companies offering trading services such as electronic energy trading platforms (e.g. Endex).

The distribution of National level RTD Programmes on the ICT sector for the energy efficiency in buildings is reported in Figure 5-7. Austria, Denmark, Finland, Ireland and The Netherlands and UK have developed National programmes that cover all the five thematic areas. National level RTD Programmes in Italy and Spain cover four thematic areas, while in France, Greece and Sweden National level RTD Programmes cover three thematic areas. Belgium, Portugal and Romania seem to give more emphasis on two thematic areas especially on 'Integration technologies'.

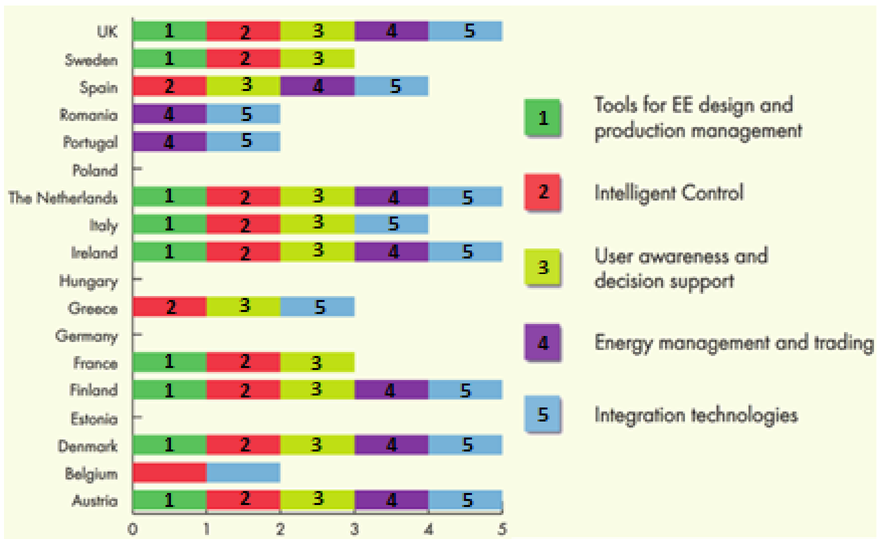

Figure 5-7: Distribution of National Research Programmes among the thematic areas.

5.6.4. **Non-EU countries**

The focus on ICT for Energy Efficiency in Buildings is growing fast in other parts of the world too. Seven countries have been assessed in this analysis, one for each continent (excluding Asia, for which three countries have been considered). The selection was also based on the economic and technology progress development of the countries. The aim of including these countries in this analysis, is to draw up the scenario analysis of programmes focusing on this field in non-EU countries. The following non-EU countries have been analysed:

Table 5-7: Non-EU Countries analysed.

Non-EU Countries			
Australia	Brazil	China	Japan
South Korea	USA	South Africa	

Figure 5-8: Ranking of thematic area covered at non-EU level.

The distribution level RTD Programmes on the ICT sector for the energy efficiency in buildings at non-EU level is reported in Figure 5-8.

'Tools for EE design and production management' (7 Programmes) and 'Intelligent Control' (7 Programmes) are the most covered areas at non-EU level, followed by 'User awareness and decision support' (6 Programmes) and 'Integration technologies' (6 Programmes). The 'Energy management and trading' area is the least covered one (5 Programmes).

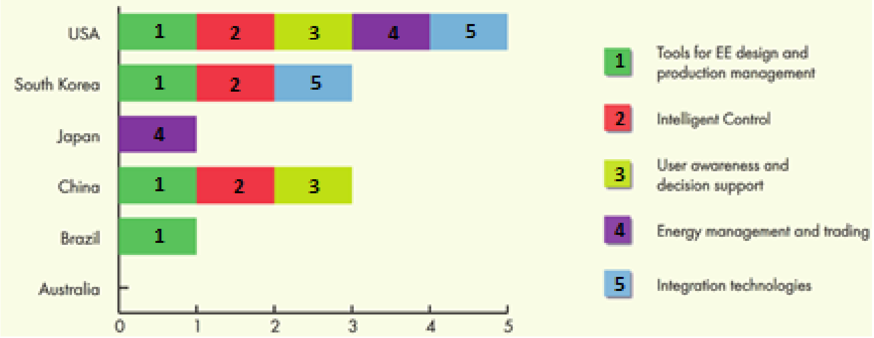

Figure 5-9: Distribution of non-EU Research Programmes among the thematic areas.

5.7. *European RTD projects on ICT for Energy Efficiency in Buildings*

The below tables show the relevant information on the available results from recently closed and ongoing projects within FP7 programmes (ENERGY, ENV, ICT, NPM, SME) and CIP programmes (ICT-PSP and IEE) related to the impact of ICT for Energy Efficiency in Buildings. From the 78 identified projects, 62 projects belong to FP7 framework, and 16 to the CIP framework, as shown in Table 5-8.

Table 5-8: Research Projects Framework Distribution.

Framework	Thematic Area	No. of Projects
FP7	Cooperation and Capacities programme	54
	Energy Efficient Building Public and Private Partnerships (EeB PPP)	6
	ARTEMIS	2
CIP	Information Communication Technologies Policy Support Programme (ICT-PSP)	12
	Intelligent Energy Europe	4

Figure 5-10 represents the level of coverage of the five thematic areas, defined by REEB (Ref. 1), in European projects.

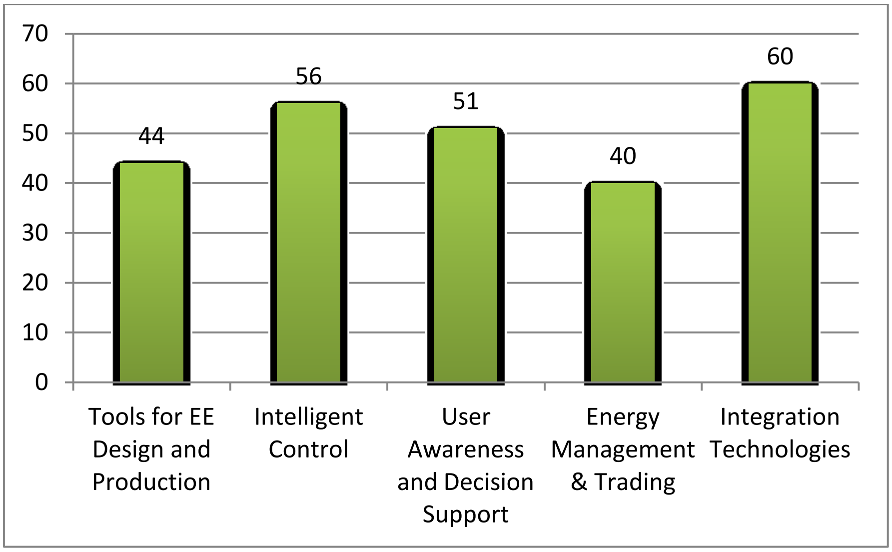

Figure 5-10: Level of coverage of ICT4E2B thematic areas by European project.

This classification indicates that there is a predominant interest of RTD projects in three ICT4E2B thematic areas, Intelligent control, User awareness & decision support and Integration technologies, with a slight predominance of the latter. Respectively, 71 per cent, 65 per cent and 77 per cent of the total number of projects considered are related to these three areas.

Then the remaining two areas follow, Tools for EE design and production and Energy management and trading, by showing similar results: respectively 56 per cent and 51 per cent of the total number of papers are related to these areas.

It is interesting to note that the category Energy management and trading is the last one in the ranking. Normally energy management innovation is carried out by energy suppliers, utilities and service providers such as ESCOs, who seem to be not fully aware of the potential of ICT solutions.

In addition, the investigation showed how the thematic areas and related subcategories and research topics are involved in research activities on the ICT4E2B domain.

The lack of standardisation in the energy, construction, and ICT sectors was the first result retrieved performing the qualitative analysis. This open issue is a need for all the five thematic areas. In fact, it is possible to verify how several projects aim to participate and contribute in standardisation efforts by:

- developing common guidelines and regulations for the monitoring and control of energy consumption and power demand,
- developing energy management systems integrated with design tools and smart metering systems,
- sharing common performance metric and policy marker to better support the actions performed by the final user of an efficient building.

A schematic representation of the results retrieved by the qualitative analysis is provided in the following tables. Nevertheless, for each thematic areas it is possible to highlight the following:

- **Tools for EE design and production management:** the need for the integration between simulation and modelling tools with a BMS is tackled by some projects in order to reduce the existent gap.
- **Intelligent control:** considering the four subcategories that belong to this thematic area, it is clear that the research commitment to QoS is less than to the other subcategories. The current state of the art of ICT tools and solutions used to perform QoS do not need further innovation.
- **User awareness and decision support:** the results demonstrate interest and some focus on this area that covers a very wide domain on ICT4E2B, although some actions on behavioural change need to be implemented.
- **Energy management and trading:** just as the considerations provided by the quantitative analysis, the qualitative analysis confirms that this category is currently not covered as widely as other thematic areas.
- **Integration technologies:** the attention is focused on a small set of new advanced technologies, identified as useful to integrate the other technologies developed for the other four areas.

Table 5-9: Results on Tools for EE design and production management.

Thematic Area	Research Topic Addressed by RTD Projects
Tools for EE design and production management	**Design** • Development of intelligent 3D design tool that allows the exploitation of mock up of 3D; • ICT sub system integration into CAD/FM design tools; • Implementation of a simulator and modelling tool, including dynamic models for energy producing, storing and using units that provide decision aid when designing or retrofitting energy infrastructures at the building domain; • Use intelligent touch table to show the end-user the results of design process and to facilitate an easy interaction between end-users. With this system it is possible to increase user awareness on the effective benefit of the design process. **Modelling** • Development of models to enable energy efficient topology management in distributed systems. • With emphasis on dynamic reconfiguration capabilities of resource management devices as key non-functional capability to cope with the legacy challenge by the use of heterogeneous communication networks able to integrate power line techniques, wireless and wired sensor and actuator network technologies; • Development of specialized ontology for multi-system integration of BIM. **Production management** • Numerical models of energy conversion and storage technologies, and numerical model to balance decentralised energy (electrical and thermal) generation with storage.

	Performance estimation • Development of new business and cost models that consider the entire life cycle of a building and incorporate the benefits of reduced operating costs and green house-gas emission; • Approach entails development of tools for measuring and analysing building energy profiles, based on user comfort needs and to use and manage the energy usage within the building throughout its life cycle; • Simulation software tools allowing emulation of District Energy Networks through the integration of simulated as well as real data sets; • A simulation model calibration methodology for uncertainty mitigation using measured data is also under development; • Algorithms for automatically generating control strategies (BEMS) to optimise performance as measured through relevant performance indices. Depending on the cost function selected, the control algorithms are automatically generated for the particular problem.

Table 5-10: Results on Intelligent control.

Thematic Area	Research Topic Addressed by RTD Projects
Intelligent control	**Automation and Control** • Develop an integrated electronic system to monitor different buildings, technical building services, electronic devices and operations in order to optimise and integrate all maintenance functions; • Development of intelligent sensor-based data monitoring; • Development and novel use of nano-materials, aiming to increase energy performance in heating, ventilation, air conditioning (HVAC) and lighting systems, and to improve indoor air quality using catalytic purification; • Use of smart sensors and Radio Frequency Based Technology (RFBT)

	• Developing novel high performance devices with electronic operation of an auto-regulated natural ventilation system and electronic insulating night blind powered by solar power. **Monitoring** • Development of new innovative domestic smart metering technology; • Development of local platform showing the resource and device integrator part, enabling the interoperability of sensors, actuators and meters; • System implementation will require the development of an HW platform that will use a combination of wired and wireless sensing technology to facilitate easy and cost-effective retrofit of devices and infrastructure in existing premises to monitor and control energy usage; • Design and implementation of an energy resources virtualisation environment and appropriate semantics to be used for building energy management applications. **Quality of service** • Research on diagnosis such as detection of malfunctioning equipment, non-optimal performance of buildings; • Secure communication inside the built environment. **Wireless Sensor Networks** • Development of wireless sensor nodes including multi-source energy harvesters, small factor fuel cells, and energy efficient RF front end with radio triggering capability; • Sensor networks able to collect real-time information detecting environmental and maintenance-oriented parameters of performance from lighting and HVAC services.

Table 5-11: Results on User Awareness and Decision Support Area.

Thematic Area	Research Topic Addressed by RTD Projects
User awareness and decision support	**Performance Management** • Performance analysis and optimisation should be implemented by the use of the information collected during the monitoring, to implement corrective/optimisation measures and improve the energy efficiency; • Forecasting of energy demand, by taking into account not only the current building operation conditions but also its expected evolution, which depends on the weather forecast and the scheduled home usage profile; • Development of a multi-dimensional visualisation system of parameters of building operations and data sharing from technical systems; • Definition of performance metric and policy marker; • Use of product Integrated Virtual Energy Laboratory (IVEL) as quantifying tool for measuring energy performance, consumption and costs throughout building's life cycle; • Development of Decision Support System (DSS) that exploits comprehensive and transferable indicators easily understood by urban planners. **Behavioural change by real-time pricing** • Create a paperless online solution for construction workers to easily display up to date drawings and other construction related materials on site; • Development of simple and clear interfaces to show evidence and demonstrate the cost recovery based on the achieved energy savings and energy efficiency improvement; • Development of intelligent and usable e-learning system to change residents' behaviour as a result of ICT, in order to increase its added value.

	Visualisation of energy use • Multimodal user interface; • Dissemination of energy consumption information in an attractive way by using accessible interface.

Table 5-12: Results on Energy management and trading.

Thematic Area	Research Topic Addressed by RTD Projects
Energy management and trading	**Building and District Management** • Design and implementation of energy management system, for self configuring automated building systems, targeting the usability requirements of three user-groups: – power distribution network operators – residential users – communication network operators; • Exploitation of in-home energy management strategies and forecast algorithm • Microgrid energy management • Intelligent local management enables participation to energy markets **Smart grids** • The real-time controller, data collection module, low cost hardware including, primarily, wireless sensors and data loggers/ transmitters, which will be deployed at the building over a period of time and facilitate the collection of data, which will form the one foundation on which the sourcing decisions may be taken; • Neighbourhood management will also include management of the heat and electricity network for efficient integration of renewable energy sources to the distributed systems; • Smart grids for demand response capabilities of renew-

	able electricity generation and supply chain; • Specify applicable services and develop the interconnection methods, the machine-to-machine (M2M) interfaces and the primitive-based communication techniques. They should allow communication-level ubiquitous networking and applicability of offering advanced energy-management and control services, bundled with other "smart-home" and "smart-building" services.

Table 5-13: Results on Integration technologies.

Thematic Area	Research Topic Addressed by RTD Projects
Integration technologies	**Process integration** • Definition and initial instantiation of architectures and communication platforms to enable the flexible and evolvable interoperation of systems, including sensors, actuators, information systems, control systems and commercial systems across multiple domains and multiple vendors and service providers. **System integration** • Development of the SOA based platform and implementation and integration of the prototypes of the services for MSI, KM and TEL; • IPv6 Wireless technologies for smart metering, integration to enterprise systems, and control network; • Design and develop "Agent" platform. This will be an HGi based, sophisticated, yet low-cost monitoring/remote-control platform, integrating both an intelligent electricity metering device, a remote-managed appliances/white-goods controller and a communication module; • Lightweight web services (REST); • The coordination is based on a service-oriented model for the middleware, then initiating a cooperation task becoming a task of service composition; • Research on artificial intelligence and decision-making methods and, where necessary, develop new techniques specifically to solve energy saving prediction and recommendations.

5.8. **Summary**

This chapter provides an update of the state of the art on ICT for Energy Efficient Buildings both at scientific and industrial level. It also provides an update of the European RTD Projects and research frameworks focusing on ICT for Energy Efficiency in Buildings. Projects were analysed at National level in the EU countries, and also in some non-EU countries.

The analysis clearly shows how at both quantitative and qualitative level there is a homogeneous distribution of research activities that involve the five thematic areas, defined in REEB (Ref. 1) and then used in ICT4E2B Forum classification, without a predominant involved area.

Many of the RTD programmes cover most of the terms of the ICT4E2B Forum classification. In particular it is important to highlight that the area Intelligent control predominates at EU and non-EU level; this is consistent with REEB finding (Ref. 1).

The area Intelligent control predominates at EU and non-EU level, while the area Energy management and trading category is the least covered. It is possible to assume that in general Energy management innovation is carried out by energy suppliers, utilities and service providers such as ESCOs, apparently without stressing the potential support that could be provided by ICT solutions.

5.9. ***References***

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6. Vision

Introduction

The previous chapter provided an update of the state of the art on ICT for Energy Efficient Buildings both at scientific and industrial level, as well as an update of the European RTD Projects and research frameworks focusing on ICT for Energy Efficiency in Buildings. But where do we go from here? What are the next steps? What is the future of ICT42B? This chapter outlines the main priorities for the development of ICT in Energy Efficiency in Buildings as envisioned in the ICT4E2B Forum project. The vision for each of the five thematic themes were generated from input from the stakeholders prioritisation workshops and further shaped by the project partners' expertise and the expert advisors group. Together, these insights demonstrate what developments are expected and desired in the next ten years in the various areas related to the building life cycle, and how all stakeholders can contribute to make this happen.

In this chapter the main findings of the envisioned future are presented in five different roadmaps, one per thematic area. Each roadmap shows where we are today -the state of the art – the priorities – what is needed- in the short (two years), medium (five years) and long-term (ten years), and the vision we are aiming at the near future. In addition, the drivers, barriers and impact for this transition in the short, medium and long-term are identified.

The generated input builds on the results obtained from the previous REEB project (Ref. 1), the European strategic research Roadmap to ICT enabled Energy Efficiency in Buildings and construction, and the EeB PPP Multi-Annual Roadmap (Ref. 2).

Although new technologies were not identified – this was not the aim of the investigation- the developments in interoperability and standardisation might lead to the consolidation of existing technologies. An increasing focus and overall change to user-centric and district level solutions can be seen in the different roadmaps. Systems at both building and district level have to take into consideration the growing need for flexibility to allow energy management solutions to be adjusted to the different needs of different end-users.

6.1. *Vision for the five thematic areas*

The ICT4E2B Forum vision for ICT-supported energy efficiency of buildings in the short, medium and long-term is displayed in Figure 6-11.

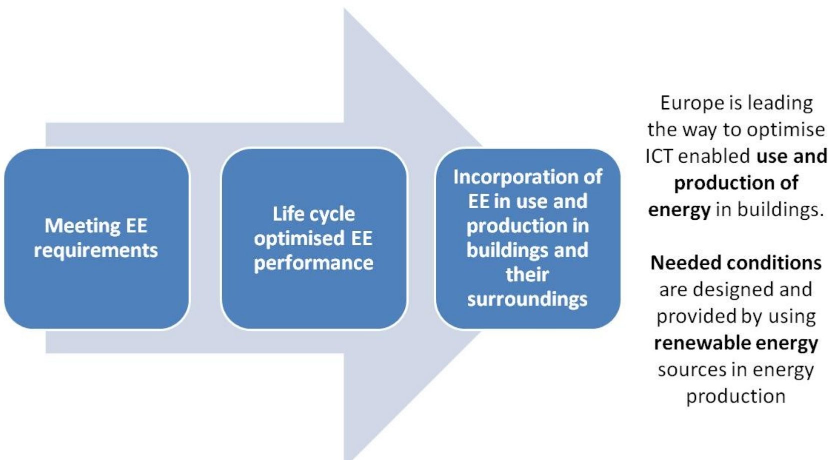

Figure 6-11: Vision for ICT enabled Energy Efficiency (EE) in the short, medium and long-term.

In the ICT4E2B Forum, just as in REEB (Ref. 1), five thematic areas have been identified. The main ICT4E2B vision for each thematic area is resumed in the following table:

Table 6-14: Visions by thematic areas.

Thematic area	Vision
EE design and production management	Integration of various functions, tools and communication between stakeholders during all phases of design and production; Contractual practices including valid verification of EE; Self-learning/adapting system applied to design; Validation and certification of simulation software

	tools; Procurement contracts/solutions based on models and life cycle EE performance.
Intelligent control	Collaborating subsystems in buildings and optimal predictive control; Collaborating buildings at district/neighbourhood and city level, interaction with the smart grid; Self-diagnostics systems with high degree of monitoring while guaranteeing security and respecting privacy; Building controls are derived and tuned based on dynamic building models that through simulation show nominal energy consumption.
User awareness and decision support	Tools/applications exploit real-time energy consumption information and help the different stakeholder to define the level of efficiency of the building; Visualisation of energy use will be ensured by using Internet-enabled, smart, and usable interfaces e.g. smartphones, and intelligent applications which provide useful suggestions to change habits to adjust energy consumption and costs.
Energy management and trading	Flexible building energy management adjustable to users as well as external needs (based on location, energy pricing etc.) Integration of intelligent devices and accurate forecasting by context information integration; Interoperable energy management solutions beyond standalone systems/buildings; Real-time energy management depending on Key Performance Indicators; Real-time Demand-Response depending on local resource availability; Buildings should collaborate with the local district for energy efficiency; Collaboration of buildings with each other; Collaboration with the smart grid markets.
Integration technologies	Parallel processes, smooth and smart workflow and tight control; New applications to support all these needs allowing different experts work together in a project; Early detection of anomalous energy consumption

	and/or malfunction of individual components by using embedded diagnostics methods, which are capable of running on local controller devices; Standardised data models and real-time communication protocols are allowing all the stakeholders to develop their devices without problems of interoperability; Knowledge of all stakeholders involved in construction and energy efficient buildings issues will be shared between them using inter-organisational knowledge platforms that contain all the information organised by term and will offer an easy way to be consulted.

6.2. *Tools for EE design and production management*

The energy use of a building is mainly determined in its design stage. The integration of model based tools and systems provide perhaps the greatest potential for ICT and energy efficiency in buildings. A large variety of applications and tools is available for the design of buildings. However, they are mainly designed with limited flexibility and lack interoperability.

The needs and expectations for this thematic area include activities focused on the development of computer-aided solutions to support the design of integrated systems (Advanced Design Support Tools and Design Integration). They also include tools to improve the efficiency of production planning, procurement, logistics, site management (Production Management) and energy simulation packages to support energy performance estimation in the design phase (Performance estimation tools) and advanced Simulation and Modelling tools.

Past and recent research in this area has focused on the development of Ontology and Semantic Mapping. This research made a substantial contribution towards Systems Interoperability and Design Integration. Research findings were used to progress with the development of Building Information Models (BIM). The current use of BIM is mainly for file based data exchange while data sharing using model servers in under early development. Whereas the benefits of BIM-based energy analysis have been demonstrated in several research projects, there are still problems related to data quality and maturity. Methods for data validation are needed.

The end-users' behaviour is not always considered in the design phase, even though it has become clear over time that the inclusion of the end-users from the beginning will support them to become active players in the energy markets related to buildings and neighbourhoods. Users of buildings should therefore not only be informed about their energy consumption through real-time information, their behaviour should be anticipated and addressed in the earlier design phase.

For process and production management in construction, various software tools are used. This has resulted in the existence of many different formats that are usually not compliant with each other. The main aspects addressed for production management are related to timing, costs and contracts.

The roadmap on Tools for EE design and production management is shown in Table 6-15. It includes a general view on the current state of the art and the expected progress in the short, medium and long-term.

Table 6-15. Roadmap on Tools for EE design and production management.

State of the art	Short-term		Medium-term	Long-term	Vision
Design: Discipline-oriented analysis and configuration management tools with discipline specific applications.	Enhancement of existing design tools with EE features, EE aspects to catalogues of materials and products.	Tools for EE conceptual design, model-based CAD tools, interoperable interfaces.	Intelligent product catalogues, semantic search, libraries of best practices and reference design solutions, visualisations of EE design alternatives, long-term archival and revival of BIM and other digital data, tools for validation of EE-compliance to building codes.	Tools for configuration, management, self-optimising models, contractual and legal validity of BIM, and digital information.	Integration of various functions, tools and communication between stakeholders. Anticipation of end-user behaviour during the design phase. Contractual practices including valid verification of EE. Self-learning design system. Validation and certification of simulation software tools. Contracts based on models and life cycle EE performance.
Production management: Tools for scheduling, costing, procurement, logistics.		Material and product tracking systems, e.g. RFID, WSN etc.	Tools to optimise production EE as part of life cycle, collaboration platform for concurrent building engineering, model-based product design and production, agreeing and integrating information flows across the value network.	Tools for rapid and flexible project team formation, contract configuration and management, model driven workflows, model-based as-built information available for operation and maintenance.	
Modelling: Document oriented tools that can extract and elaborate relevant modelling information directly from the documents produced at earlier phases of the project.	Enhancing current BIM models (IFC) with standardised EE attributes, model analysis and validation tools for EE, modelling of building energy profiles.		Enhancement of data models (ontologies) to cover EE aspects. Modelling of local energy generation related to buildings: PVs, wind power, RES, storage etc., modelling of user profiles.	BIM servers for collaborative BIM based design. Integration of design models (BIM) with operational near-real-time information, integration of building and district level models.	
Performance estimation: Distinct tools for cost estimation, life cycle assessment and energy simulation.	Definition of EE performance indicators, easy input from tools for simulation, reduced time.		Standardise performance indicators at European level, performance estimation tools, comparison of performance information at the different stages of design-production-operation, development of test cases for simulation software tools.	Tools to estimate EE in a quantified and verifiable way - sufficient for performance based contracts, models, methods and tools to estimate EE performance of urban districts consisting of buildings, local generation and storage, interacting with energy grids, use of test cases to develop validation/ certification process.	

6.2.1. **Drivers, barriers and impact**

The five thematic areas are each divided in vision, key research topics, drivers, barriers and impact.

- Driver: Why would one want to move to the next level?
- Barrier: What prevents one from moving to the next level?
- Impact: What are the benefits from moving to the next level?

The identified drivers, barriers and impact for tools on EE design and production management are summarized in Table 6-16.

Table 6-16: Drivers, barriers and impact for tools for EE design and production management.

	From state of the art to short-term	**From short to medium-term**	**From medium to long-term**
Drivers	Increase EE requirements.	Enhanced regulations for EE of buildings. Integration of renewable energy sources.	EE driven business.
Barriers	Lack of interoperability. Unavailability of EE data about materials and products.	Incompatibility of business incentives for design versus whole life cycle performance. Simulation tools are not fully interoperable with design tools.	Prevailing business models focusing on delivery costs instead of value to client.
Impact	Compliance EE regulations at lowest cost.	EE services. Life cycle optimised buildings.	Branding EE design and production services.

6.3. *Intelligent control*

The first step to decreasing energy consumption is to understand where the energy is being consumed. Since buildings are the largest energy consumers it is important that they have the connectivity and functionality to interoperate with the smart grid.

From all five thematic areas, Intelligent control envisions most of all the collaboration of buildings at district and city level. Its focus is on building controls which automatically interact with the smart grid to exploit the maximum amount of renewable energy sources on-site, and to level the use of energy to avoid peaks. This kind of communication with the smart grid needs sensors with the required sensitivity and accuracy at reasonable cost for a large scale deployment.

It is expected that in the future full energy-efficiency benefit is harvested through collaborating subsystems (such as light or ventilation) and optimal predictive control, balancing the trade-off between comfort and energy consumption, local production and storage.

The systems will have self-diagnostics and provide a high degree of monitoring while protecting the privacy of individuals. Building controls are derived and tuned based on dynamic building models that through simulation show the nominal energy consumption.

The roadmap on Intelligent control is shown in Table 6-17. It includes a general view on the current state of the art and the expected progress in the short, medium and long-term.

Table 6-17: Roadmap on Intelligent control.

<table>
<tr><th>State of the art</th><th>Short-term</th><th>Medium-term</th><th colspan="2">Long-term</th><th>Vision</th></tr>
<tr><td>Automation and Control:
Standardised solutions for control.</td><td>Coordinating algorithms between applications.</td><td>Predictive control considering weather forecast, make building controls responsive to smart grid interactivity.</td><td colspan="2">Generate optimal building controls from BIM, optimal controls on district and city level, equipment manufacturers provide dynamic models of their products enabling simulation.</td><td rowspan="4">Collaborating subsystems and optimal predictive control.

Collaborating buildings on district and city level and interaction. with the smart grid.

Self-diagnostics systems with high degree of monitoring while protecting privacy of individuals.

Building controls are derived and tuned based on dynamic building models that through simulation show the nominal energy consumption.</td></tr>
<tr><td>Monitoring:
Monitoring as a standard component in a modern BMS and measurements used for building control stored in trend logs.</td><td>Decrease production and deployment cost of basic communicating meters.</td><td>Increased data collection while protecting the privacy of individuals, embed more intelligence in sensors to perform local analysis.</td><td colspan="2">Sensors are built in the fabric of the building.</td></tr>
<tr><td>Quality of service:
Basic self-diagnosis commonly available in automation control products.
Large quantity of self-diagnosing functionality with associated alarms.</td><td>Enforce that detected problems get attended, develop real-time algorithms for energy-efficiency diagnosis.</td><td>Embed self-diagnosis in sensors, self-diagnosing equipment detecting suboptimal energy performance.</td><td>Use of virtual reality for diagnosis and repair.</td><td rowspan="2">Inclusion of sensors and diagnostics in building materials.</td></tr>
<tr><td>Wireless sensor networks: Wireless technologies for building automation available, but there’s a lack of interoperability between different vendors.</td><td>Develop communication standards ensuring multi-vendor interoperability and supporting battery-less low-power devices, establish cost-effective deployment procedures.</td><td>Define standardised roles and services for sensors, automatically adapting network topology.</td><td></td></tr>
</table>

6.3.1. **Drivers, barriers and impact**

The identified drivers, barriers and impact for Intelligent control are summarized in Table 6-18.

Table 6-18: Drivers, barriers and impact on Intelligent control.

	From state of the art to short-term	From short to medium-term	From medium to long-term
Drivers	Dynamic and increased energy prices.	Local production and storage of energy.	Regulations and standards for energy efficiency.
Barriers	ROI must be proven. More focus on capital investment than operational cost.	Insufficient interoperability. Security and privacy concerns.	End-user acceptance.
Impact	Increased demand for a Building Management System (BMS).	Sustained energy efficiency.	Improved district energy management.

6.4. *User awareness and decision support*

Information is the key issue in supporting decisions and creating awareness. It is easily available, comprehensible and useful for further operations through various interfaces and taking advantage of gaming and mixed reality. ICT supports understanding, capturing and formalising the customer/client needs. ICT also serves to formulate the needs into requirements, conveying them to all stakeholders and validating compliances.

The main roles of ICT in User awareness and decision support are to:

- provide information to the users of buildings, owners, facilities managers, local authorities and urban planners about energy consumption;
- enable occupants to control devices in buildings to decrease consumption;
- make occupants aware on how their activities will influence energy use in the short and long-term;
- motivate and support behavioural change by highlighting other factors that affect energy usage (such as building materials during renovation);
- gather information about many environmental factors (temperature, humidity, CO_2 concentration, solar radiation, etc.);
- predict possible energy use.

The roadmap on User awareness and decision support is shown in Table 6-19. It includes a general view on the current state of the art and the expected progress in the short, medium and long-term.

Table 6-19: Roadmap on User awareness and decision support.

State of the art	Short-term	Medium-term	Long-term	Vision
Performance Management: Standardised indicators available for assessing energy performance of buildings, systems and components. Performance audits, labelling and continuous commissioning are supported by recorded data of real-time performance.	Technologies capable of balancing the levels of automation and individual choice, performance database.	Integrating personal energy use between different building contexts, privacy and security, automatic tuning of the intelligent BMS (parameterisation), energy parameters database, and interoperability with real-time diagnostics, where estimated (designed) and observed (actual) performance can be compared.	Combination of ICT tools with non-ICT tools for obtaining an effective impact, heterogeneity of the system, definition of common standards and units.	Easy to use tools, connected in a network, exploit real-time energy consumption information and help different stakeholders to influence the level of efficiency of the building.
Visualisation of energy use	Attractive interfaces for energy visualisation, increase the knowledge of end-user needs, identification of the level of individual knowledge that each user must have about the buildings in which he lives or works.	Exploit social pressure as a driver for motivating users on energy efficiency themes.	Organise training sessions and e-learning websites for final users involvement.	Visualisation of energy use will be ensured by using Internet accessible and usable interfaces connected in a network. They provide suggestions on how to change behaviour and decrease energy consumption and costs.
Behavioural change: Technologies are available to improve the level of user awareness.	Real-time Internet accessibility to control your building consumption, development of energy bank database.	Increasing involvement of building users and owner on the use of BMS. Reduce technological costs for end users. Definition of attractive energy contracts for end- users.	Daily energy consumption plan aimed at optimisation and making the activities scheduled by users more energy efficient.	

6.4.1. **Drivers, barriers and impact**

The identified drivers, barriers and impact for User awareness and decision support are summarized in Table 6-20.

Table 6-20: Drivers, barriers and impact of User awareness and decision support.

	From state of the art to short-term	**From short to medium-term**	**From medium to long-term**
Drivers	Cost reductions.	Motivation of the users.	Social pressure.
Barriers	Right balance between individual choice and automated, intelligent controls.	Lack of European standards and common unit metrics.	Peoples habits.
Impact	ICT will be combined with non-ICT tools for energy efficiency available to users.	Users and owners make informed decisions about the building and its use.	Life cycle optimised buildings. Users as active players in energy market.

6.5. ***Energy management and trading***

Energy management and trading are seen as key issues in the emerging future energy infrastructure. In this future perspective buildings are no longer seen as standalone entities, but as an integral part of a larger ecosystem both internally (within the subsystems of the building) and externally (with other entities such as buildings, transportation system and public lighting). Within the buildings, intelligent devices are monitoring and actuating autonomously the buildings behaviour to achieve the desired functionality. Users are now able to interact with the building to fulfil their needs, even temporarily. This is possible only because a new generation of energy services enable this kind of interaction.

Buildings also strive towards energy optimisation at district or smart city level. As such they may collaborate with nearby buildings in order to achieve energy efficiency. Additionally they collaborate within a smart city infrastructure, with, for example, a transportation system. In this case buildings will use their resources (such as internal operations or electric vehicles on their parking place) to assist the optimal electricity network operation and act as an energy-balancing partner. With the emerging opportunities that the smart grid offers, buildings can now buy and/or sell electricity on available marketplaces. They can intelligently plan their energy behaviour and even provide new revenue sources to their owners by adjusting their behaviour to demand-response conditions from the electricity grid.

The buildings of the future will be part of a live ecosystem that will heavily interact and collaborate with users and external entities to optimally manage their energy footprint locally and as part of the ecosystem.

The roadmap on Energy management and trading is shown in Table 6-21. It includes a general view on the current state of the art and the expected progress in the short, medium and long-term.

Table 6-21: Roadmap on Energy management and trading.

State of the art	Short-term	Medium-term	Long-term	Vision
Building Energy Management: Several (also commercial) isolated solutions available dealing with energy management in buildings (not interoperable). Limited number of smart appliances available.	Adoption of open and interoperable solutions, service wrapping of existing functionalities, information exchange between building's subsystems, enhancing and extending existing energy management.	Deployment of intelligent devices, provision of (mobile) Internet based user services, adjustment of the building behaviour to users' plans.	Provision of complex user services, real-time fully automated energy management and adjustment to dynamic conditions, collaboration with other buildings and systems.	Flexible building energy management adjustable to users' and external needs. Integration of intelligent devices and accurate forecasting of energy use by context information integration (information coming from different sources). Interoperable energy management solutions beyond standalone systems/buildings. Real-time energy management depending on Key Performance Indicators. Real-time demand-response depending on local resource availability. Buildings should collaborate with each other, with the smart grid markets and with the local district for energy efficiency.
District Energy Management: Energy Monitoring solutions available (not real-time), energy info is available in silos of solutions for the different district systems, hardly any energy services for the citizens.	Energy monitoring at district level, opening of functionalities and provision of services.	District Energy services for end-users, deployment of district-wide energy management, citizen energy services and best practices, privacy and security assessment tools.	Real-time adjustment and optimisation of district energy management to conform to KPIs, full integration with all parts of the smart city (including public infrastructure, transportation etc.), energy simulation and model availability for districts.	
Smart grid and the Building Environment: Smart metering is an issue under development, energy monitoring services for citizens.	Smart metering, energy awareness via monitoring services.	User participation on district energy marketplaces, value energy added business services.	Real-time demand-response solutions, participation of prosumers to aggregated energy trade groups and free energy trade, automated Intelligent Energy management for virtual groups of buildings/users, market-driven energy services.	

6.5.1. **Drivers, barriers and impact**

The identified drivers, barriers and impact for Energy management and trading are summarized in Table 6-22.

Table 6-22: Drivers, barriers and impact of Energy management and trading.

	From state of the art to short term	**From short to medium term**	**From medium to long-term**
Drivers	The key drivers may come from the quest towards energy management and efficiency and be driven by key stakeholders such as DSO, facility management, etc. The enabling ICT technologies may be provided by the market players who will drive them.	Economic reasons at EU level.	Policy/Regulation at EU level.
Barriers	Security and privacy concerns. Lack of awareness on innovation for energy management as part of an ecosystem. Lack of open standardised approaches for energy data monitoring and assessment. Lack of policies and incentives at national and European wide level. Inadequate work-	ICT tools for enabling interaction between all stakeholders.	Lack of business adaption and availability of value added services.

	force skills and training.		
Impact	Significant impact in BEMS could be achieved, tackling energy efficiency and with the first results already available in the short-term.	Significant impact in District Energy Management could be achieved in the mid and long-term leading to optimal energy management at district and smart city level.	Integration with the smart grid and optimal consideration of the building environment and advances in other sectors e.g. construction could act as an enabler for energy efficiency.

6.6. *Integration technologies*

When we discuss technology solutions, it is clear that there is not one all-encompassing solution. The integration of technologies and standardised protocols are the most valuable assets for energy efficiency measures.

The dynamic nature of design projects requires parallel processes, smooth workflow and tight control. New applications give support to all these needs and will allow different experts to work together with improved coordination of processes and shared control of all the projects. This kind of applications will offer smart workflows that will be synchronised depending on the status of the project without any help. They will do it automatically.

Embedded diagnostics methods, capable of running on local controller devices, will be developed to allow early detection of anomalous energy consumption and/or malfunction of individual components (dampers, valves, coils, etc.) in sub-systems such as air handling, heating, cooling, or lighting. Load management algorithms will consider future energy consumption and based on that will try to adjust the consumption curve by shifting or curtailing some of the loads. In case of system optimisation, the control strategy will use the information about the operation states, loads, weather conditions, tariffs, and equipment characteristics.

Data models and real-time communication protocols will be standardised in order to allow all the stakeholders to develop their devices and make them work together. Producers will not have to worry whether their devices will be effective at the moment to plug them, because all the devices inside and outside the buildings will share the same protocols. Other domains protocols and standards will be integrated as needs and applications of buildings will increase.

All the knowledge of all stakeholders involved in construction and energy efficient buildings will be shared between them using inter-organisational knowledge platforms. These platforms will contain all the information organised by thematic area and will be easily accessible.

The roadmap on Integration technologies is shown in Table 6-23. It includes a general view on the current state of the art and the expected progress in the short, medium and long-term.

Table 6-23: Roadmap on Integration technologies.

<table>
<tr><th>State of the art</th><th>Short-term</th><th>Medium-term</th><th>Long-term</th><th>Vision</th></tr>
<tr><td>Process integration:
Rude applications to integrate different roles in a project.</td><td>Improvement of the rude applications existing in the market.</td><td>Applications that will allow the control of parallel processes by different experts involved in a project.</td><td>Development of smart workflows in this kind of applications due to the dynamic behaviour of these projects.</td><td rowspan="4">Parallel processes, smooth and smart workflow and tight control.

New applications allowing different experts to work together in a project.

Early detection of anomalous energy consumption and/or malfunction of individual components by using embedded diagnostics methods, which are capable of running on local controller devices.

Standardised data models and real-time communication protocols allow all the stakeholders to develop their devices without problems of interoperability.

Stakeholders’ knowledge will be shared using inter-organisational knowledge platforms that contain all the information organised by thematic area and will be easy to consult.</td></tr>
<tr><td>System integration:
Coexistence of various communication protocols and devices.</td><td>Systems integration from building level to neighbourhood level.</td><td>Networked Embedded software and devices are needed to control the consumption of buildings using diagnostics methods to control the devices.</td><td>Systems to predict and plan future consumptions are to be investigated.</td></tr>
<tr><td>Interoperability and standards:
Non interoperability among devices and non-complete standards.</td><td>Agreement on the protocols and communications that fit better with the needs of the vendors and the existing devices.</td><td>IPv6 adoption and further technology standards development and general adoption by most of the vendors.</td><td>All the devices inside and outside the buildings will share the same protocols.</td></tr>
<tr><td>Knowledge sharing:
Different allocations to share knowledge, difficult to find.</td><td>Use of common forums and collaboration spaces to share the knowledge.</td><td>A common platform for all the stakeholders has to be developed to allow knowledge sharing and ease the effective search of information.</td><td>Improvement of seek methods in the common platform to allow good access to huge amount of information related to all kind of fields.</td></tr>
</table>

6.6.1. **Drivers, barriers and impact**

The identified drivers, barriers and impact for Integration technologies are summarized in Table 6-24.

Table 6-24: Drivers, barriers and impact on Integration technologies.

	From state of the art to short term	**From short to medium-term**	**From medium to long-term**
Drivers	Development of IPv6 as a common protocol for communication.	Balance consumption and generation of energy in buildings, energy auto generation in buildings.	Load management algorithms to consider future energy consumption.
Barriers	Adapting the existing building to the new approaches of energy efficiency in buildings, lack of knowledge about building life cycle energy costs.	Agreement on a common protocol for communication inside and outside the buildings (because of different existing protocols and communications).	Access to knowledge generated in all the fields related to energy efficiency in buildings.
Impact	New business opportunities for ICT, energy and building sectors. Change of mentality regarding the importance of energy efficient buildings and energy costs, resulting in better implementation of building lifecycle.	Standardisation regarding communications and protocols to ease the interoperability and the communication among different devices, implementation of smart grid concept.	Sharing knowledge between all the stakeholders involved in energy efficiency, new algorithms to plan and forecast consumption in buildings.

6.7. *Summary*

The energy use of a building is mainly determined in its design stage. The integration of model based tools and systems are probably the greatest potential for ICT and energy efficiency in buildings.

The needs and expectations in the thematic area of Tools for EE design and production management include activities on the development of computer aided solutions to support the design of integrated systems, tools to improve the efficiency of production planning, procurement, logistics, site management and energy simulation packages to support energy performance estimation. Users of buildings should not only be informed about their energy consumption through real-time information, their behaviour should be anticipated and addressed in the earlier design phase.

The first step to decreasing energy consumption is to understand where the energy is being consumed. It is important that buildings have the connectivity and functionality to interoperate with the smart grid to exploit the maximum amount of renewable energy sources on-site, and to level the use of energy to avoid peaks. From all five thematic areas, Intelligent control envisions most of all the collaboration of buildings at district and city level. It is expected that in the future full energy-efficiency benefit will be harvested through collaborating subsystems (such as light or ventilation) and optimal predictive control, balancing the trade-off between comfort and energy consumption, local production and storage.

The systems will have self-diagnostics and provide a high degree of monitoring while protecting the privacy of individuals. Building controls are derived and tuned based on dynamic building models that through simulation show the nominal energy consumption.

Information is the key issue in supporting decisions and creating awareness. It is easily available, comprehensible and useful for further operations through various interfaces and taking advantage of gaming and mixed reality. Easy to use tools, connected in a network, exploit real-time energy consumption information and help different stakeholders to influence the level of efficiency of the building. Visualisation of energy use will be ensured by using Internet accessible and usable interfaces connected in a network. They provide suggestions on how to change behaviour and decrease energy consumption and costs.

Energy management and trading are seen as key issues in the emerging future energy infrastructure, in which buildings are no longer standalone entities, but an integral part of a larger ecosystem. Within the buildings, intelligent devices are monitoring and actuating autonomously the buildings behaviour to achieve the desired functionality. Users are now able to interact with the building to fulfil their needs. This is possible only due to a new generation of energy services enabling this kind of interaction.

When we discuss technology solutions, it is clear that there is not one outstanding solution. The integration of technologies and standardised protocols are the most valuable assets for energy efficiency measures. New applications allow different experts to work together in a project with improved coordination of processes and shared control of all the projects. Other key solutions include early detection of anomalous energy consumption and/or malfunction of individual components by using embedded diagnostics methods, which are capable of running on local controller devices. And finally, standardised data models and real-time communication protocols allow all the stakeholders to develop their devices without problems of interoperability.

6.8. *References*

[1] REEB Project Consortium, *ICT Supported Energy Efficiency in Construction -- Strategic Research Roadmap and Implementation Recommendations*, 2010.

[2] EeB - The Ad-hoc Industrial Advisory Group, *Energy-Efficient Buildings. Multi-AnnualRoadmap and Longer Term Strategy*, 2010, http://www.ectp.org

7. The implementation action plan

Introduction

The outcomes presented in this chapter aim to encourage a closer dialogue and a more active cooperation between researchers, end-users, practitioners, building owners, technology suppliers, and software developers. We define objectives for future research topics and recommended activities, such as multi-disciplinary research, demonstrations, dissemination, best practice promotion, education and training, innovation policies and standardisation.

Not only do we address the technical scope and expected impact in different areas, we also identify the roles and actions various stakeholders should perform towards the energy efficiency objectives.

The formulation of the ICT4E2B roadmap is based on the initial work performed within the REEB project (Ref. 1), where different stakeholders were invited to submit RTD research topics and ideas supporting the implementation and realisation of the roadmap. These proposals were analysed and consolidated into recommendations regarding different innovation stages, covering:

- Policies: regulation, taxation, setting up large-scale actions/programmes etc.
- Coordination: roadmaps, think tanks, working groups, studies, supporting innovation and research programs, facilitation of communication between different initiatives and communities etc.
- RTD: tolls for energy efficient design and production management, intelligent and integrated control, user awareness and decision support, energy management and trading, and integration technologies.
- Take-up: dissemination, promotion, awareness creation, demonstrations/pilots.
- Standardisation: interfaces, models, protocols, reference architectures etc. concerning convergence of ICT standards across sectors.
- Education and training

Implementation of these recommended actions is envisaged to lead to key industrial transformations. The role of ICT for energy efficiency in buildings will be as follows:

- Life cycle approach: Integrated design teams, using interoperable model-based tools and communication/collaboration platforms to optimise the whole life performance of buildings.
- Smart buildings: Most buildings will be smart and control themselves maintaining the required and optimal performance. They will proactively anticipate external conditions and user behaviour rather than respond reactively. Holistic operation of subsystems is supported by integrated system architectures, communication platforms and standard protocols for interoperability, sensors, and wireless control technologies.
- Construction as a knowledge based industry: Industrialised solutions are available for configuring flexible new buildings as well as retrofitting existing buildings. Customised solutions are developed by configuring reusable knowledge from catalogues within organisations and industry-wide.
- Business models and regulations are driven by user perceived value: Financing models provide incentives to stakeholder towards whole life performance of buildings. ICT tools support performance measurement, validation and holistic decision-making.

The ICT4E2B Forum followed and built on REEB output (Ref. 1) with a slightly different approach. Based on the Strategic Research Agenda, the ICT4E2B Forum identified the necessary actions for different stakeholders, including for the end-users and standardisation bodies. Achieving the target outcomes will require action in the below cross-cutting areas of integrated design, component catalogues, data models, application tools, visualisation of energy use, performance management, behavioural change, real-time analytics on energy data, smart building integration in the demand/response energy trading, Building models for control, deeper consumption energy control and energy brokerage among end-users. Some suggested roles and activities are relevant for different stakeholders and in different areas.

7.1. ***Integrated design***

Technical scope

The lifetime performance of a building is largely determined in the design phase. This is especially the case when new buildings are designed. Design for retrofitting of existing buildings is also crucial as buildings and/or their subsystems and components are renewed several times throughout their lifetime. Complex building systems need to be optimised based on multiple and often conflicting criteria. The degree to which the designed energy efficiency potential will be actually materialised, depends on the downstream life cycle stages (construction, commissioning, operation, user behaviour etc.). Therefore integration between different information sources, stakeholders and stages is of fundamental importance for design.

Target outcomes

The main RTD targets for integrated building design are interoperability of various ICT applications and the ability to share information at high semantic level between stakeholders over all life cycle stages:

- Enhancement of existing design, analysis and simulation applications as well as catalogues with energy related attributes and interoperable interfaces based on standards.
- ICT platforms to facilitate sharing of and negotiations about the evolving design information within and between organisations. The challenges include providing open access to relevant stakeholders, presenting information in context driven ways, supporting both the agreed inter-organisational transactions and internal workflows of each organisation, and protecting the IPR of semantically rich information.
- Holistic optimisation of the interactions between different subsystems considering technical, commercial, sustainability and regulatory factors.
- Methods for collaborative development of early stage design concepts and decision support with context driven visualisations.
- Tools for modelling existing buildings & facilities for retrofitting design e.g. by scanning.

- Collaborative configuration design and customisation based on reference solutions, adaptation rules and catalogues of parametric objects.
- Methods and services for very long time data archival and recovery over generations of standards, tools and storage media.
- Simulation based systems for refining requirements for highly interdependent complex systems and for validating the contributions of different subsystems to the overall energy performance in areas like complex office or public buildings and major infrastructures.
- Definition of standardised energy performance indicators that can be calculated from available design and operation data. Methods for ICT-based validation of the actual performance compared to the designed performance. Certification procedures for performance assessment software and methods.
- New design processes and collaboration forms.

Expected impact

Integrated design has direct impact on the design process itself as well as on the subsequent life cycle stages that depend on design information. The energy performance of the target system depends ultimately on the combined impact of design, materialisation and operation.

- Engagement and empowerment of relevant stakeholders in the design and decision-making process.
- Enhanced use of proven reference design solutions with less reinvention.
- Awareness and improved understanding of stakeholders about the impact of various design options and generally about the impact of ICTs on energy efficiency.
- Improved quality of design with respect to compliance to requirements, consistency, number of errors, and predictable and optimised life cycle performance.
- Better information support to the downstream life cycle stages (materialisation, operation).

Suggested roles of stakeholders in implementation

Public sector, building clients: Promote integrated design in the procurement of buildings. Require comprehensive standards-based information delivery. Promote and adopt standardised performance indicators / metrics. Develop and implement contractual conditions that incentivize the design team towards holistic life cycle performance. Promote the rights of citizens to receive information about designed buildings and to participate in consultations about them.

E2BA: Promote RTD on integrated design towards interoperable design tools, ICT infrastructures for cross-organisational collaborative engineering and contractual conditions to incentivize design teams for optimised life cycle performance of buildings. Enable the construction design sector to adopt new technologies and collaborative business models.

Construction sector companies and organisations: Establish guidelines and template agreements for integrated design covering the roles and responsibilities of stakeholders, interoperability requirements of shared design information, compliance conformance validation procedures, intellectual property rights of shared digital information etc.

ICT sector: Increase the semantic level (the input & output information) of design tools. Develop standards based interfaces. Develop ICT platforms / infrastructures that allow companies to fully manage their internal workflows (e.g. design iterations & internal approvals) using their in-house tools while interacting in a controlled way with external project partners (information releases, conformance checking, change requests, audit trail & interference resolution). Develop generic catalogues for re-usable information (products, materials, reference design solutions, best practices). Provide ICT platforms / infrastructures as services (IaaS, Infrastructure as a Service) with appropriate service contracts suitable to temporary project teams in the construction sector. Develop 3rd party trust services for information sharing and archiving.

Energy sector: Provide information about local energy provision and exchange conditions. Suggest protocols for energy management between the energy grids, local generation, storages and buildings.

Knowledge providers: Train construction professionals to collaborate and negotiate in virtual environments. Educate construction ICT experts to develop and deploy interoperable design tools and collaborative design environments. Provide information brokerage services about materials, products and services from various providers to specific target groups.

End-users: Require open access to design information about new or renovated buildings and participate in public consultations about them. Provide information to building user profiles. Participate in web-based communities (social media) to share user experiences.

Standardisation bodies: Develop and enhance standards for interoperability (IFC, IFD, IDM). Develop and standardise performance metrics (EE indicators and validation methods) based on information that is available from current and emerging ICT systems.

7.2. *Component catalogues*

Technical scope

Catalogues of materials and components are needed to support the design of (new and retrofitted) buildings and their subsystems as well as for procurement. The catalogues should provide access to versatile commercial and technical information (including e.g. energy efficiency related properties). The information contents should be at high semantic level in order to allow full exploitation of increasingly model based design tools.

Target outcomes

- Catalogues with semantic information of materials, components and reconfigurable design solutions. Parametric objects to support configuration/adaptation of generic component types for specific applications.
- User interfaces for semantic search and filtering for user and context specific data delivery.
- Standards-based interfaces / web-services for interoperability with various CAD tools and engineering applications for design, performance analysis, simulation, visualisation etc.
- ICTs for brokering information from several sources e.g. combining manufacturer specific catalogues to serve specific groups of information users (examples: architects, building services designers).
- Standardised data models of catalogue contents, in this context regarding especially energy related data e.g. embodied energy.
- Toolkits for catalogue authoring, publication and maintenance.
- New business and service models for information providers and brokers.

Expected impact

- Improved efficiency and quality of design through use of pre-existing knowledge.
- Improved energy efficiency through availability and re-usability of energy related data.
- Accelerating take-up of more sophisticated ICT due to increasing information availability.

Suggested roles of stakeholders in implementation

Public sector, building clients: Expect application of proven construction solutions when radically new solutions are not especially required.

E2BA: Promote industrialised construction supported by methods for custom design.

Construction sector companies and organisations: Develop industrialised construction and renovation methods. Publish product/solution information catalogues. Set up and operate sector-wide catalogue services.

ICT sector: Develop ICT tools for catalogue authoring, maintenance, publication, brokering between different catalogue services and user profile driven information delivery. Enhance existing design tools with support for using external catalogues, parametric and configuration management.

Energy sector: Suggest information to be provided about local generation and storage facilities.

Knowledge providers: Train/educate construction professionals on industrialised construction methods, mass-customisation and configuration design.

End-users: Require comprehensive information about buildings, their subsystems and components.

Standardisation bodies: Continued development of ICT standards for product information, regarding e.g. energy aspects and metadata for catalogue items.

7.3. *Data models*

Technical scope

Achieving energy efficiency requires holistic management of information from many stakeholders over the product (building) life cycle. Common concepts and language are prerequisites for communication between both humans and ICT systems. Agreed data models (ontologies) are needed to bridge the gaps and to enable information sharing and re-use without error-prone manual interpretation, re-entry and loss of data.

Target outcomes

- Existing data models for various application domains extended with EE specific concepts in the short-term.
- Common cross-disciplinary concepts by alignment of sector specific ontologies to support balancing of energy provision and consumption (e.g. grinds and buildings).
- Definitions of metadata of shared information in distributed collaborative design and engineering, and catalogues of materials and products.
- Standardised representation of functional/parametric product/system objects with embedded configuration/customisation logic.
- Convergence of agreed models and ontologies for different inter-related applications areas, leading to standardised data models covering energy related aspects in a broad range of applications in the long-term.
- Test cases, methods and procedures to validate the compliance of software tools and shared data with respect to agreed data models (ontologies).
- Forums bringing together developers of data models (ontologies) from inter-related application areas (e.g. buildings, process plants, grids etc.) to join forces towards harmonisation of ICT standards related to energy efficiency. The already launched activities in this area foreseen to remain necessary in the long-term.

Expected impact

- Standardised data models (ontologies) covering energy related information and interactions within and between related application areas (buildings, smart cities, energy systems).
- Improved ease of access to EE knowledge through a common ontology.
- Interoperability of design software through compliance to standardised data models.
- Improved energy efficiency through holistic optimisation using integrated information.

Suggested roles of stakeholders in implementation

Public sector, building clients: Promote access to and re-usability of building information throughout the life cycle via model based design. Specify information delivery requirements in construction projects aiming at high semantic level. Adopt digital data as contractually valid original information.

E2BA: Promote transition from paper-oriented documentation towards digital and computer-interpretable (model-based) information as a key to transform construction from a resource providing industry into a knowledge-based industry.

Construction sector companies and organisations: Define information requirements. Deploy model-based tools and require interoperability between them.

ICT sector: Develop new model-based tools and enhance the semantic power of existing tools. Comply with interoperability standards. Develop tools for analysis and compliance assessment of model-based data.

Knowledge providers: Train/educate construction professional to understand information requirements of other related disciplines.

End-users: Expect to receive customised information for different needs, regarding both logical content and presentation.

Standardisation bodies: Continued development of standards for product information regarding e.g. energy aspects.

7.4. *Application tools*

Technical scope

Application tools for design include general-purpose CAD tools with sector specific add-ons and a huge variety of specific tools for engineering analysis, life cycle performance estimation, simulation, visualisation etc. The main research needs are related to issues such as: early stage design and decision-making, enhancing the scope of existing tools to support design for EE, increased utilisation of previous good design solutions, information sharing between various ICT tools through interoperability and reducing the gap between predicted and actual energy performance of systems through holistic engineering methods e.g. simulation.

Target outcomes

- Concept design – Profiles of end-user groups regarding their requirements and energy consumption patterns. Tools for early stage conceptual design, life cycle energy performance estimation based on reference data, visualisation and decision support of design options. Methods, e.g. based on simulations, to derive detailed requirements from models of complex systems.
- Detail design – Configuration design based on templates, reference solutions, parametric adaptation rules and intelligent component catalogues. Modelling existing buildings/facilities for retrofitting design e.g. using scanning. Context aware visualisation of the evolving detail design solutions for cross-disciplinary decision-making.
- Engineering analysis and simulation applications – Domain specific application tools enhanced with energy related aspects and interoperable interfaces based on standards. New tools for integrated assessment and visualisation of costs, environmental impact, comfort etc. Holistic simulators of complex systems such as buildings interacting with energy systems and infrastructures. Procedures and test cases for certifying software tools.
- Supply network management, production planning and management – Decision support for selection of materials, components, suppliers and production strategies (e.g. offsite vs. onsite production considering logistics and local resources). Simulation supported real-time production man-

agement. Context related multimedia content provided to workers on portable devices. Inter-enterprise ICTs supporting coordination towards contractual goals, including energy efficiency.
- Visualisation and decision support – Besides informing stakeholders about real-time progress towards EE objectives and highlighting trade-offs between environmental and economic concerns, ICTs should also proactively suggest options for decision-making.

Expected impact

- Awareness and ability of stakeholders to make grounded decisions about design and production options.
- Reusability of proven solutions through model based design technology, interoperability, configuration design and intelligent catalogues.
- Improved quality of design through holistic consideration of the interactions between various subsystems.
- Certified software tools reducing the gap between predicted and actual system performance.

Suggested roles of stakeholders in implementation

Construction sector companies and organisations: Shift from in-house tools increasingly to commercially supported tools. Provide test cases for comparing different tools within an application area.

ICT sector: Develop methods for validation of software tools. Integrate isolated tools and improve their interoperability. Develop toolkits and business models for co-development of ICT-applications with domain experts.

Knowledge providers: Educate construction sector ICT experts to specify and develop ICT applications.

End-users: Specify requirements for the contents and visualisation of design information.

Standardisation bodies: Provide methods and procedures for software validation.

7.5. *Visualisation of energy use*

Technical scope

Definition of new interactive graphical user interfaces exploiting the new types of mobile devices such as smartphones and tablets. Availability of broadband Internet connection wherever the user is located.

Target outcomes

- Innovative and easy to use attractive interfaces and mobile applications to visualise real-time data related to energy consumption and to predict real time costs. This has the purpose to increase the knowledge about real end-user needs, and to identify the level of individual knowledge that each user must have about the buildings in which he lives or works.
- New IT solutions and embedded sensors will come from other technology fields where user-centred design approaches are fundamental.

Expected impact

Energy consumption visualisation allows end-users to oversee and control their own consumption, allows detecting potential misuses of buildings due to a lack of awareness of the users, potential disorders and/or pathologies of the monitored building. Moreover, conditional maintenance approaches can bring added value in guaranteed performance contracts.

Suggested roles of stakeholders in implementation

Public sector, building clients: Increase the adoption and diffusion at local, national and international level of the rules for allowing a better visualisation of end-user private energy data.

ICT sector: Information is the key issue in supporting decisions and creating awareness. The role of ICT operator is twofold:

- develop intuitive and easy to use user interfaces for visualisation of energy consumption
- collaborate with energy and public sector to the dissemination and communication of the potentialities of the new visualisation tools to general public

Energy sector: Providing incentives to customers facilitating the installation of energy visualisation displays in the buildings.

Knowledge providers: Organisation of training sessions and development of e-learning websites to disseminate the advantages related to new visualisation energy tools to final users.

End-users: To be stimulated by the new visualisation tool to reduce the energy consumption and change behaviour towards better energy efficiency.

Standardisation bodies: Creating awareness providing specific guidelines particularly those that affect data security protocols to guarantee the protection of user private energy data during the visualisation procedure.

7.6. *Performance management*

Technical scope

Development of models and methods to allow relevant stakeholders to assess the energy efficiency in buildings in order to improve their EE performance, such as Artificial Intelligence methods and Genetic Neural Network. Definition of new reliable and easy to use data management system for managing energy performance data.

Target outcomes

- Multi-dimensional visualisation system of parameters of building operations and data sharing from technical systems.
- Virtual 3D energy simulation environment as quantifying tool for measuring energy performance, consumption and costs throughout building's life cycle.
- Sensing techniques, possibly coupled with dynamic building simulation models.
- Innovative web/mobile applications to monitor buildings' energy indicator.

Expected impact

- Promote behavioural changes in building residents, building operators and owners by highlighting other factors that affect energy usage (like demographics, family composition).
- Users can pinpoint vampire devices, times of high or low consumption, and wasteful patterns of energy use by monitoring buildings' energy consumption in real time with a web/mobile application.

Suggested roles of stakeholders in implementation

Public sector, building clients: Enable the adoption and diffusion of performance management system at neighbourhood, city, regional, national and international level.

E2BA: Promote the use of a European observatory on energy performance involving a European database.

Construction sector companies and organisations: Guarantee of measured energy performances to meet pre-set contractual values used as benchmark. Energy performance management achieves a high level of comfort and health (thermal comfort, acoustics, indoor air quality and accessibility in particular).

ICT sector: Develop effective methods to assess the impact of ICT solutions on the energy efficiency in buildings. Creation of a European database on energy performance measurements.

Energy sector: Support public sector actors in the definition of actions useful to perform a widespread adoption of ICT performance management system among end-users.

Knowledge providers: Promote the use of performance management tools among designers, engineers, architects and urban planners. Provide training actions for building residents on the utility of performance management tools to evaluate the EE of the buildings in which they are living.

End-users: Shall be educated in the subject of energy and cost saving opportunities given by the adoption of performance management tools, for example to pinpoint vampire devices, times of high or low consumption, and wasteful patterns of energy use.

Standardisation bodies: Introduce harmonised European standards that enable a reference metric to be used across different European countries. Make a complete list with energy features for each material and product, for instance, in the field of construction.

7.7. *Behavioural change*

Technical scope

Introduction of new multimedia devices act to provide suggestion/recommendation to the end-user concerning the impact of their daily behaviour in energy saving in an attractive way.

Target outcomes

- Evidence and comparison of investment and operational costs with the achieved energy savings and energy efficiency improvement.
- Intelligent and multimedia system that facilitate the changing of residents' behaviour as a result of ICT in order to increase its added value. These systems will help citizens to improve their behaviour by learning new ways of conducting daily activities.
- With user-friendly websites users could, easily from their house, learn the merits and methods of energy conservation in order to reduce energy consumption and save money.
- Tools for comparison at neighbourhood level or with similar unities, e.g. family composition and user density within the building, by exploiting census for protecting privacy.

Expected impact

- More accurate broadcasting of information to users of buildings, owners, facilities managers, local authorities and urban planners about energy consumption.
- Awareness of occupants on how their activities will influence energy use from short and long-term perspectives.
- Motivation and support for behaviour changes by highlighting other factors that affect energy usage (such as demographics and family composition).

Suggested roles of stakeholders in implementation

Public sector, building clients: Create legislation and incentives to promote the use of behavioural change tools between building owners and residents to decrease the energy consumption. Define regulation that allows sharing of end-user consumption data (e.g. in a neighbourhood or thematic community) while protecting privacy.

Construction sector companies and organisations: ESCOs (Energy Service Companies) will be able to show evidence to building owners and residents of the comparison of investment, operational costs and energy savings that can be achieved through the adoption of behavioural change ICT tools.

ICT sector: Develop ICT solutions, mobile access interface, multimedia tablets, that are extremely user friendly as well as relevant and effective. These solutions should also enable 'social sharing', according to specific regulation about data privacy management that is currently missing and should be released, since 'social pressure' is one of the best means of getting people involved in changing behaviour.

Energy sector: Providing real-time pricing information to end-users.

Knowledge providers: To adopt and promote the develop usable software application (accessible by pc and mobile devices as smart phones/tablets) aimed at changing residents' behaviour. Promoting change in collective behaviours and tackling large groups.

End-users: Shall be surrounded by display, control panels and multimedia system useful for a better understanding of the advantages related to the modification of everyday behaviour for decreasing energy consumption.

Standardisation bodies: Creating awareness and acceptance on the necessary changes, providing specific guidelines, particularly those that affect lifestyles and behaviour.

7.8. *Real-time analytics on energy data*

Technical scope

A significant amount of information (Big Data) will be generated by the future smart buildings. Real-time analytics need to be done to assess the business value of data collected and to take the relevant business decisions. High-performing cloud-based systems, new parallel algorithms, efficient Complex Event Processing (CEP) technologies etc. need to be significantly advanced.

Target outcomes

- IT architectures and tools for high performance real-time analytics of Big Data.
- New distributed analytics algorithms and services.
- Mobile end-user applications.

Expected impact

- Correlation of business aspects and energy consumption.
- Cost effective plans considering energy aspects.
- Improved decision-making processes through visibility of energy.
- New service providers in the knowledge economy.

Suggested roles of stakeholders in implementation

Public sector, building clients: Promote open interoperable data exchange formats. Promote privacy-preserving data collection.

E2BA: Consider the value by real-time analytics on huge data and acquisition of potential new insights. This is applicable for consumers, districts and smart cities. Integrate real-time analytics for better monitoring and understanding of energy usage at system level, in order to enhance decision-making.

Construction sector companies and organisations: Consider in decision-making the analysis of data for the optimal case in business.

ICT sector: High performance cloud computing approaches. Real-time communication and computation platforms for large amounts of data.

Energy sector: Provision of fine-grained data over time (eventually even minute-wise or less) and nature (at device level, building level etc.).

Knowledge providers: Education on understanding analysis results and the impact on tasks.

End-users: Integration of results in their everyday life. New applications with insights in their own infrastructure.

Standardisation bodies: Develop/enhance standards for interoperable and efficient information exchange and processing.

7.9. *Smart building integration in the demand response energy trading*

Technical scope

Future smart buildings are seen as an integral part of smart cities and can have a significant impact on their Demand Response programmes. Hence they should be seen as stakeholders participating in DR concepts and energy trading at neighbourhood or city level. DR and energy trading may assist at system-level (e.g. neighbourhood or smart city) to better manage its resources and adjust dynamically to its needs. New IT tools and methods for assessing a system-wide view are needed, just as basic services and applications that will enable DR and local market electricity trading.

Target outcomes

- New technologies and applications enabling smart buildings to act as balancing partners in the smart grid e.g. sophisticated energy management systems that can monitor and control context-aware energy processes
- New systems considering energy costs and trading their energy flexibility as a new revenue.
- New approaches in interacting with the building's users and consider their tasks/schedule (e.g. via their calendar) for energy planning at building level.

Expected impact

- Business performance not only cost-optimised but also energy-optimised (or a mix of various Key Performance Indicators).
- Integration of new infrastructures (smart buildings) in real-time energy management at building and grid level. For instance consideration of in-building produced energy with its needs and external acquisition.

- New revenue sources for smart building managers/owners.

Suggested roles of stakeholders in implementation

Public sector, building clients: Promote energy-aware buildings. Enable trading of electricity at neighbourhood or city level. Integration of all energy aspects beyond electricity, including heating/cooling into an system-wide view.

E2BA: Consider the buildings as active part of a larger ecosystem and not as standalone isolated entities. Buildings of the future will be able to communicate and adjust their state based on internal and external interactions (e.g. with a market, other buildings, energy efficiency guidelines).

Construction sector companies and organisations: Consider what the ICT capabilities of future buildings should be and enable them at all phases (design, construction etc.).

ICT sector: Real-time monitoring and real-time energy management approaches for the smart building lifecycle should be considered.

Energy sector: Integrate interactions with energy flexible infrastructures (such as the smart buildings).

End-users: Integration of results in their everyday life. New applications with insights in their own infrastructure.

Standardisation bodies: Interact with the buildings and share information to benefit from energy efficiency approaches.

7.10. *Building models for control*

Technical scope

During the operations phase dynamic building models can be useful in a real-time sense, e.g. to make optimal control decisions including weather forecast and variable energy pricing. Such models are preferably of low complexity to minimise computational effort for optimisation and tuning for a specific building. Research efforts are needed to find efficient model formats and to validate them, using real-world data.

Target outcomes

- Developed mathematical model formats suitable for building optimization.
- Algorithms to tune the model parameters for a specific building and application.

Expected impact

- Ability of buildings to rapidly balance energy flow between consumption, storage and local production.
- Buildings as active components in the smart grid.
- EE through optimal control decisions.
- Forecast of energy need as function of weather and energy data.

Suggested roles of stakeholders in implementation

Public sector, building clients: Promote local production and storage of energy in buildings. Local production emphasizes the need of balancing energy flow, for which this technology is a core component.

E2BA: Promote RTD on model generation methodology suited for building control.

Construction sector companies and organisations: Development of building component models that could feed the generation of control models.

ICT sector: High performance cloud computing approaches. In general, more optimal control can be achieved with access to more computing power, and thereby better EE. Additionally, off-site computations could include multi-site optimisations.

Energy sector: Promote local production and storage of energy in buildings. Local production emphasises the need of balancing energy flow, for which this technology is a core component.

7.11. *Deeper consumption energy control*

Technical scope

In order to use energy more efficiently, the end-user needs timely and precise information about his home consumption, including detailed information about each household appliance energy consumption.

Wireless sensor networks are needed to monitor the energy consumption by sensing the devices in households. Monitoring all these devices through the building energy management is essential for the visualisation of energy use by end-users, and will allow them to make decisions regarding this information.

The results from the EU research project e-Diana (Embedded Systems for Energy Efficient Buildings, Ref. 2) showed that it is possible to improve energy efficiency and optimise building energy consumption by 25%, providing real-time measurement, integration and control by raising user awareness about his household appliance energy consumption.

Target outcomes

- Integrated BMS with wireless sensor networks.
- Monitoring and Metering System will provide information on power consumption of the different household appliances through two main user interfaces:
  - PC or TV
  - Mobile (through smartphones)

Expected impact

- By using this information, end-users will be aware of consumption of each device, taking into account reduce this.
- Reductions in energy bills by selecting the hours with lower price to switch on devices that use large amounts of energy.

Suggested roles of stakeholders in implementation

Public sector, building clients: Public bodies must raise the awareness of citizens and companies to use more sophisticated systems to control the energy consumption.

E2BA: A better Efficient Energy Consumption control should be added to the section on the theme "Performance monitoring and management" of the EeB roadmap.

Construction sector companies and organisations: Establish guides to install the wireless sensor networks in the buildings.

ICT sector: Development of new BMS and interfaces for end-users.

Energy sector: Clear establishment of energy prices per hour.

End-users: Should be aware of this new information and use it to take decisions on energy consumption.

Standardisation bodies: Develop one main standard to unify all the existent standards and protocols used by different companies on the market.

7.12. *Energy brokerage among end-users*

Technical scope

Buildings are capable of generating their own energy, however, in some cases they cannot consume all the energy they generate, and in other situations they need more energy than they can produce. It is important to take these points into account, and supply energy brokerage technologies to new buildings.

The EU research project Encourage (Ref. 3) is actually developing an intelligent gateway with embedded logic supporting inter-building energy exchange.

These energy brokerage mechanisms will provide an intelligent gateway with embedded logic supporting inter-building energy exchange. This brokerage agent will communicate directly with other buildings and local producers to negotiate the possible use of the electricity produced locally in their premises.

Target outcomes

- New algorithms in charge of predicting the load and generation of energy in each building.
- Internal technological platforms in buildings in charge of the brokerage of energy, which will enable effective interaction with other buildings, local producers, or electricity distributors.

Expected impact

- Real-time energy management in relation with consumption and generation in each moment.
- Real-time Demand Response depending on local resource availability.
- Collaboration of buildings and local energy producers.
- End-users with active participation in the future smart grid environment.
- Allowing effective interaction with other buildings, local producers, or electricity distributors.

Suggested roles of stakeholders in implementation

Public sector, building clients: Public bodies must raise the awareness of citizens and companies to use more sophisticated systems to control the energy consumption.

E2BA: Enabling Energy brokerage among end-users should be added to the section on the themes of "Performance monitoring and management" and "Smart-cities initiatives" of the EeB roadmap.

Construction sector companies and organisations: Establish guides to install the energy brokerage mechanisms in the buildings.

ICT sector: Improvement of brokerage technologies from other sectors to be adopted in buildings.

Energy sector: ESCOs should take into account new business models related to energy brokerage.

Standardisation bodies: Develop/ harmonise standards for BMS, local energy systems and grids.

7.13. *Summary*

Achieving energy efficiency requires holistic management of information and big data from many stakeholders over the building lifespan.

The outcomes presented in this chapter aim to encourage more active cooperation between various stakeholders and provide each of them with suggestions for further research topics and necessary activities to undertake towards the energy efficiency targets. These activities include multi-disciplinary research, demonstrations, dissemination, best practice promotion, education and training, innovation policies and standardisation. Achieving the target outcomes will require action in the following cross-cutting areas:

Integrated design

The lifespan performance of a building is largely determined in the design phase. This is especially the case when new buildings are designed. The main RTD targets for integrated building design are interoperability of various ICT applications and the ability to share information at high semantic level between stakeholders over all life cycle stages.

Component catalogues

Catalogues of materials and components are needed to support the design of new and retrofitted buildings and their subsystems, just as for procurement. The information contents should be at high semantic level in order to allow full exploitation of model based design tools.

Data models

Agreed data models are needed to bridge the gaps between stakeholders and to enable information sharing and re-use without error-prone manual interpretation, re-entry and loss of data.

Application tools

The main research needs in application tools are related to early stage design and decision-making, enhancing the scope of existing tools to support design for EE, increased utilisation of previous good design solutions, information sharing between various ICT tools through interoperability and reducing the gap between predicted and actual energy performance of systems through holistic engineering methods e.g. simulation.

Visualisation of energy use

This area requires a definition of new interactive Graphical User Interfaces exploiting the new types of mobile devices such as smart phones and tablets. There is also a need for availability of broadband Internet connection wherever the user is located.

Performance management

Development of models and methods allow relevant stakeholders to assess the energy efficiency in buildings in order to improve their EE performance. There is need for a definition of new reliable and easy to use data management system for managing energy performance data.

Behavioural change

The introduction of new multimedia devices will provide the end-user -in an attractive way- suggestions and recommendations on the impact of their daily behaviour in energy saving.

Real-time analytics on energy data

A significant amount of information will be generated by the future smart buildings. Real-time analytics need to be done to assess the business value of the data collected, and to take the relevant business decisions. High-performing cloud-based systems, new parallel algorithms and efficient Complex Event Processing (CEP) technologies need to be significantly advanced.

Smart building integration in the demand response energy trading

Future smart buildings are seen as an integral part of smart cities and can have a significant impact on their Demand Response programmes. Hence they should be seen as stakeholders participating in DR concepts and energy trading at neighbourhood or city level.

Building models for control

During the operations phase dynamic building models can be useful in a real-time sense, e.g. to make optimal control decisions including weather forecast and variable energy pricing. Research efforts are needed to find efficient model formats and to validate them, using real-world data.

Deeper consumption energy control

The end-user needs timely and precise information about his home consumption, including detailed information about each household appliance energy consumption. Wireless sensor networks are needed to monitor the energy consumption by sensing the devices in households, which is essential for the visualisation of energy use.

The necessary actions to achieve take-up in the field of energy efficient buildings were identified for different stakeholders, including for the end-users and standardisation bodies.

7.14. ***References***

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8. Conclusion

Buildings in Europe are responsible for 40 per cent of the energy consumption and 36 per cent of the CO_2 emissions in the EU. Improving the energy performance of buildings is the key to achieve the EU climate and energy objectives, namely the reduction of a 20 per cent of the greenhouse gases emissions by 2020 and 20 per cent energy savings by 2020. Substantial steps have been taken towards this objective. Nonetheless, Commission estimates from February 2011 suggest that the EU is on course to achieve only half of the 20 per cent objective.

In 2011, the European Commission proposed a new set of measures for increased energy efficiency, to fill the gap and put the EU back on track. The strengthening of research investments in Information and Communication Technologies (ICTs) in relation to the building sector plays an essential role. The enhanced ICT systems will support the needs for developing innovative business models and services that can provide continuous and precise information to decision makers, industries and policy makers.

Within this framework the ICT4E2B Forum project intended to promote a better understanding of the use of ICT to support informed decision-making in the delivery and use of energy-efficient buildings and districts. The outcomes presented in this book are based on the above mentioned project results and are aimed to encourage a closer dialogue and a more active cooperation between researchers, end-users, practitioners, building owners, technology suppliers, and software engineers.

The work carried out builds on the research results previously carried out in REEB project (REEB Project Consortium, *ICT Supported Energy Efficiency in Construction -- Strategic Research Roadmap and Implementation Recommendations*, 2010).

The intention was to update the existing REEB roadmap, consisting of the Vision Strategic Research Agenda (SRA) and the Implementation Activity Plan. This previous work provided a solid ground for the extended research roadmap presented in this book, which defines objectives for future research topics in the short, mid and long-term.

A significant group of various stakeholders was involved into roadmap development through workshops, community building activities and web questionnaires. They participated in the activities from the very first beginning, and thus profoundly discussed and validated the priorities addressed in the roadmap.

The main results of the roadmap can be summarised as follows:

- **Tools for EE design and production management -** There is a need to draw attention to the development of building EE tools apart from mainstream building information modeling (BIM) and computer aided design (CAD) software as the independent BIM-CAD tools focus on detail design methods with limited data interfaces. The notable gap identified is tool-based linkage between BIM software and ICT related building components. Existing tools in the market for performance estimation of a building are not considered reliable enough to be contractually practiced and regulated, thus it is necessary to develop appropriate data flow among the series of tools used for performance estimation.
- **Intelligent control -** Currently there are mature and standardised solutions for control of heating, ventilation, lighting and blinds. These controls are, however, commonly independent and the benefit from coordination e.g. with access control and power distribution is usually unexploited. Ongoing RTD efforts include the development of new innovative domestic smart metering technology and local platform with both resource and device integration, enabling the interoperability of sensors, actuators and meters. When a building automation system is available, there is usually a large quantity of self-diagnosing functionality with associated alarms. There are also more advanced services that attempts to identify failures based on historical building data. We need intelligent control with access to open data and correlation of events.
- **User awareness and decision support -** Standardised methods and indicators are available for assessing and benchmarking the energy performance of buildings, systems and components. But it still remains an open issue and regulation will need to play a fundamental role to obtain a reference metric that can be used across different European countries. There is the need to make occupants aware of how their activities will influence energy use from short and long-term perspectives. The reduction of technological costs will help to increase the diffusion of equipment, the devel-

opment of efficient distributed architecture like smart grid, and the global reduction of energy consumption. Clear information should be provided so that the users are able to modify the setup of their electric equipment modifying some parameters of their own system; in this manner the electronic equipment should be automatically piloted to the right configuration.

- **Energy management and trading -** Smart grid prosumers will be able to not only better manage their energy based on real-time information they acquire, but also buy and sell the energy they produce online. There is a need to provide interoperable energy management solutions beyond standalone systems, building collaboration with their users (adaptive behaviour), cross-system collaboration within a building, and lifecycle management of energy services. The available energy information remains in silos of solutions for the different district systems and there are hardly any energy services for the citizens. Several gaps are identified, for example real-time monitoring of energy, and energy management, collaborative district-wide approaches, energy management for emerging trends e.g. buildings and electric cars, security and privacy issues, district wide energy services, and modeling and simulation tools. Currently smart metering and energy monitoring services for citizens are under development. Identified gaps include the lack of real-time demand-response, metering analytics, integration of buildings with prosumers and the energy market, as well as the need to develop the security and privacy issues.
- **Integration technologies -** There are many system technologies available that claim to be an open system technology: each one has its peculiarity and standards, but only few of them have gained wide acceptance and application. However, they have very different networks, software (communication protocols and configuration tools) and hardware requirements. In order to ease the interoperability and the communication among different devices, protocols to achieve this should be standardised. Data models and real-time communication protocols should also be open/standardised to allow all the stakeholders to develop their devices without problems at the moment to plug them and make them work together. To be effective, organisations need not only to negotiate their migration from a knowledge sharing (first generation) to a knowledge nurturing (second generation) culture, but also to create sustained

organisational and societal values. A common platform for all the stakeholders involved would significantly aid movement in this direction.

In addition to the roadmap, the ICT4E2B Forum project identified activities for different stakeholders to perform on the road to achieving the energy efficiency targets, including best practice promotion, education and training and innovation policies. The project also created an overview of the current European Projects and National R&D Frameworks (EU-27 and beyond) on ICT for energy-efficient buildings. The results show that many of the RTD programmes cover most of the terms of the ICT4E2B Forum classification. The area Intelligent control predominates at EU and non-EU level; consistent with REEB finding.

When technology solutions are discussed, it is clear that there is not one all-encompassing solution. The integration of technologies and standardised protocols, for example, are very valuable assets for energy efficiency measures. Due to the strong need to share building information at high semantic level, the ICT4E2B Forum looked beyond technology solutions and included the non-technological barriers such as European regulation, contractual practices and the involvement of end-users. Only the full picture and a clear understanding of all stakeholders' constraints, priority needs and capabilities will bring us to the next level of an energy-efficient and a more sustainable Europe.

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