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**ICT 4 E2B Forum-European stakeholders’ forum crossing value and innovation chains to explore needs, challenges and opportunities in further research and integration of ICT systems for Energy Efficiency in Buildings**

**D2.4 Final research roadmap**

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| Prepared by: | Matti Hannus, Isabel Pinto-Seppä, (VTT)  Andrea Cavallaro,Christian Mastrodonato (DAPP)  Francesc Pelegrin, Charles Bastos Rodriguez (ATOS)  Oskar Nilsson (SCHNEIDER)  Stamatis Karnouskos (SAP) |
| Verified by: | Christian Mastrodonato. (DAPP) |

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Executive summary

Information and communication technologies (ICTs) offer versatile potentials in the building and construction sector to achieve energy savings and CO2 reduction targets in Europe. In some areas, like building automation and control, direct impacts of ICT on energy usage can be readily seen. ICT has also significant indirect impacts in other areas. In order to exploit the potentials of ICT there is a need to identify the most promising technologies. Future research efforts should be prioritized accordingly.

Broad research topics for construction were identified in the Strategic Research Agenda of the European Construction Technology Platform (ECTP 2005). These were complemented by the Multi-annual Roadmap of the Energy Efficient Buildings European Initiative (E2B EI 2010).ICT specific research topics were defined by the Strat-CON project as a contribution to the ECTP Focus Area Processes and ICT (Strat-CON 2007, ECTP 2008). This work was continued by the REEB project with specific focus on energy efficiency [1].

This document presents the roadmap work conducted under ICT 4 E2B Forum project, The European stake­­holders’ forum, crossing value and innovation chains to explore needs, challenges and oppor­tu­ni­ties in further research and integration of ICT systems for Energy Efficiency in Buildings. The project continued the work of the REEB project by:

* bringing together relevant stakeholders to identify and review the needs in terms of research and systems integration;
* widening the vision beyond the technical point of view to address also societal, economic, market, end-user and several other perspectives;
* updating the REEB research roadmap;
* promoting the use and further development of ICT for improved energy efficiency of buildings.

The roadmap work consists of Vision, Strategic Research Agenda (SRA) and suggestions for implementation activities. The SRA consists of prior division of five distinct thematic areas, each divided into vision, key research topics, drivers, barriers and impacts. Furthermore, the document includes the synergies of the ICT4E2B Forum project with Energy-efficient Buildings (EeB) PPP Multi-annual Roadmap [2],

This work is majorly based on results obtained from the previous deliverables of future application scenarios (D2.1), prioritised gaps (D2.2); draft research roadmap (D2.3) and findings from the REEB project [1]. The initial version of the roadmap (D2.3) was presented at the validation Workshops (organized by WP4) with the experts group for feedback on contents and priorities.

The ICT 4 E2B Forum vision for ICT supported energy efficiency of buildings in the short, medium, and long term is displayed in Figure 1. Further Table 1 resumes the main ICT4E2B foresighted vision for each thematic area and the categories in each of these areas. The roadmap for ICT supported energy efficiency of buildings can be summarized in simple terms as follows:

* **Short term:**ICT enables the connectivity and interoperability of individual buildings and networks and is used to ensure that existing and new buildings meet the current and emerging requirements for energy efficiency defined in relation to the surrounding infrastructure and climate.
* **Medium term:**Design, production, retrofitting, operation, use and demolition are empowered and enabled by re-configuration, optimisation, and access to real-time information, decision support and interoperability with easy to use interfaces.

**Long term:**ICT enables and supports new business models and processes driven by energy efficiency. Buildings have evolved from energy consumers to “prosumers” (producer + consumer).

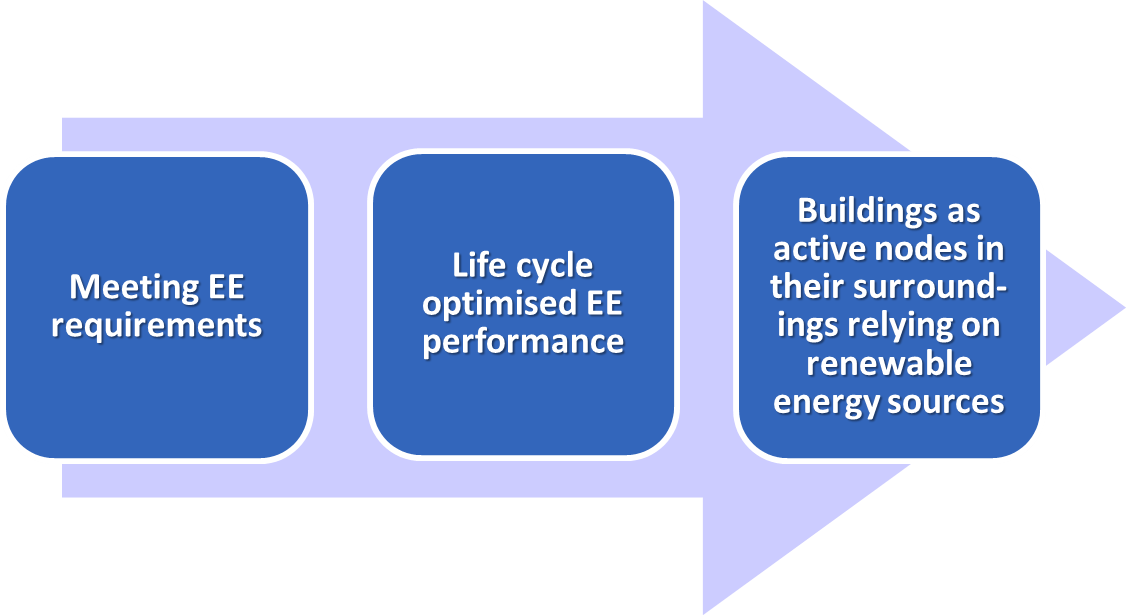


Figure 1: Updated vision for ICT enabled energy efficiency in short, medium and long term (cf. REEB [1])

ICT will contribute to the energy efficiency of buildings mainly via design tools, automation and control systems and decision support for various stakeholders.

ICT 4 E2B research Roadmap defines objectives and timeframe for future research topics and activities The implementation action plan suggests roles and actions for the main stakeholders from the public sector and building clients, ICT and Energy sector, knowledge providers, end-users and, standardisation bodies.

Previous work conducted in REEB and EeB provided a solid ground for the research roadmap presented in this document. New technologies were not identified; however the developments in interoperability and standardisation might lead to the consolidation of existing technologies. An increasing focuses and overall change to user-centric and district level solutions can be seen.

Table 1: ICT 4 E2B visions for each thematic area

|  |  |
| --- | --- |
| **Thematic area** | **Vision** |
| EE design and production management | Integration of various functions, tools and communication between stakeholders.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. |
| Intelligent control | 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. |
| User awareness and decision support | Smart, fun and easy to use and effective energy management tools, which exploit real time energy consumption/production information and help the different stakeholders to achieve their tasks while being energy efficient at building level.  Visualisation of energy use anytime anywhere with management capabilities and integration in multi-domain applications and services. Energy analytics and decision support systems that provide useful suggestions to change habits to decrease energy consumption and costs. |
| Energy management and trading | Flexible building energy management adjustable to user’s as well as external needs.Integration of intelligent devices and accurate monitoring & forecasting by context information integration. Interoperable energy management solutions beyond standalone systems/buildings. Real-time energy management depending on Key Performance Indicators (e.g. cost, efficiency, etc.). Participation in Real-time Demand-Response approaches – new revenue generation.Buildings collaborate with their users and the local district for energy efficiency. Collaboration of buildings with each-other, smart city infrastructure and participation in energy marketsTowards autonomic smart buildings with self-management, self-monitoring, self-healing and self-optimization. |
| Integration technologies | New applications to support parallel processes, smooth and smart workflow, and tight control allowing different kind of experts work together.  Early detection of anomalous energy consumption and/or malfunction of networked devices by using embedded diagnostics methods.  Cost reduction for installing EE devices and reduction of problem interoperability among EE devices by using standardised data models and real-time communication protocols. Definition of a “one shop point” platform that collects information coming from construction, energy and ICT fields and allows the sharing among stakeholders from these fields. |

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# Introduction

Information and communication technologies (ICTs) offer versatile potentials in the building and construction sector to achieve energy savings and CO2 reduction targets in Europe. In some areas, like building automation and control, direct impacts of ICT on energy usage can be readily seen. ICT has also significant indirect impacts in other areas. In order to exploit the potentials of ICT there is a need to identify the most promising technologies. Future research efforts should be prioritized accordingly.

Broad research topics for construction were identified in the Strategic Research Agenda of the European Construction Technology Platform (ECTP 2005). These were complemented by the Multi-annual Roadmap of the Energy Efficient Buildings European Initiative (E2B EI 2010). ICT specific research topics were defined by the Strat-CON project as a contribution to the ECTP Focus Area Processes and ICT (Strat-CON 2007, ECTP 2008). This work was continued by the REEB project with specific focus on energy efficiency [1].

#### Purpose

The objective of this document is to present the finalICT4E2B research roadmap and to define objectives for future research topics and activities. This consists of five distinctive roadmaps based on prior division of thematic areas followed from REEB project (refer section 1.3).Furthermore, the document includes the synergies of the ICT4E2B Forum project with Energy-efficient Buildings (EeB) PPP Multi-annual Roadmap [2],

This work is majorly based on results obtained from the previous deliverables of future application scenarios (D2.1), prioritised gaps (D2.2); draft research roadmap (D2.3) and findings from the REEB project [1]. The initial version of the roadmap (D2.3) was presented at the validation Workshops (organized by WP4) with the experts group for feedback on contents and priorities.

The implementation action plan, presented here,defines topics and objectives for research, standardisation, and education, as well as actions for industry (construction sector, ICT sector, and energy sector), policies and regulations.

#### Document structure

The document is structured in the following sections:

* Section 1: Introduction presents the purpose and general background of the deliverable D2.4 Final research roadmap.
* Section 2: Elaborates the synergies of ICT4E2B Forum project with existing EeB PPP Multi-annual Roadmap.
* Section 3: Represents consolidated vision.
* Section 4: Details the updated strategic research agenda.
* Section 5: Describesthe updated implementation plan.
* Section 6: Includes the conclusions followed by acronyms and terms and references. The section focuses onthe description of the main findings. It also summarizes the general feedback from the validation workshops which is described in detailed in the deliverable D4.6.

#### Baseline

The main inputs at the start of the work were:

* Existing roadmap on ICT contributions to improve energy efficiency of buildings by REEB project was used as baseline for ICT4E2B forum project. [1]
* EeB PPP Multi-annual Roadmap and Longer Term Strategy. [2]
* Previous deliverables from ICT4E2B Forum
  + D1.1 Classified research areas [3]
  + D1.2 Initial analysis of the state-of-the-art [4]
  + D1.3 Initial Analysis of research projects [5]
  + D2.1 Application Scenarios [6]
  + D2.2 Prioritised Gaps [7]
  + D2.3 Research roadmap [8]

#### Methodology

This document is an updatefor the existing REEB roadmap [1], consisting of Vision, Strategic Research Agenda (SRA) and suggestions for implementation activities. The SRA consists of prior division of five distinct thematic areas, each divided into vision, key research topics, drivers, barriers and impacts. The drivers, barriers and impacts are related to transition between short-medium-long terms as following:

* 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 document includes 5 ‘roadmap’ tables based on the 5 main categories and 17 sub-categories of the prioritized research topics (Table 2). Each table describes briefly:

* State of the art.
* Short-term research priorities: 3 years to industrial usage; adaptation, testing and take up of new technologies.
* Medium-term research priorities: 6 years to industrial usage; development of new applications and incremental technologies.
* Long-term research priorities: 9 years to industrial usage; including radical technical developments.
* Vision: desirable future situation based on currently foreseen developments.

Table 2: Identified five main categories and related subcategories

|  |  |
| --- | --- |
| Main category | Subcategory |
| 1. Tools for EE design and production | * Design * Production management * Modeling * Performance estimation |
| 1. Intelligent control | * Automation & control * Monitoring * Quality of service * Wireless sensor networks |
| 1. User awareness & decision support | * Performance management * Visualization of energy use * Behavioral change |
| 1. Energy management  & trading | * Building energy management * District energy management * Smart grids and the built environment |
| 1. Integration  technologies | * Process integration * System integration * Knowledge sharing * Interoperability & standards |

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Partners (VTT, Schneider, D’Appolonia, SAP and Atos) used the baseline information, results obtained from previous deliverables and REEB roadmap [1] to derive the updated SRA.

The initial version of the roadmap was presented,for feedback on contents and priorities, at the validation workshops with the experts from different stakeholders groups. A web questionnaire was also developed and is open as used in deliverable D2.2 Prioritised gaps. Thisresearch and technology development (RTD) prioritisation process and the roadmap validation results are summarized in section 6.2.anddescribed in detailed in the forthcoming deliverable D4.6.

# Synergy with EeB PPP Multi-annual Roadmap

The Energy-efficient Buildings (EeB) PPP, launched under the European Economic Recovery Plan [9], will devote approximately € 1 billion in the period 2010-2013 to address the challenges that the European construction sector and its extended value chain are facing in their ambitious goal of researching new methods and technologies to reduce the energy footprint and CO2 emissions related to new and renovated buildings. This represents the initial and highly strategic step of a longer term set by the industry to create more efficient districts and cities while improving the quality of life of European citizens.

Within this framework the Energy Efficient Building Association (E2BA) [10], in its role of industrial interlocutor of the European Commission in the EeB PPP, and in particular the Ad-hoc Industrial Advisory Group (AIAG) has developed a multi-annual roadmap with the objective of identifying the main research priorities for industrial stakeholders and to define a long term strategy in the framework of energy efficient building technological area.

The methodology for EeB Roadmap development used by the AIAG has been based on the broad consultation of E2BA members and the enlarged network of stakeholders. In fact through the E2BA members and their multiplying effect, a large community of local authorities, capital providers, developers (designers, engineers, contractors), supply chain (materials and equipment suppliers), investors and owners as well as end users have been reached, providing a broad overview of the research needs for the future of the sector. Indeed, over 200 contributions highlighting research challenges and opportunities have been gathered from more than 100 E2BA member organisations, organised in five working groups. It is very important to underline that this stakeholder-based approach has been taken as reference and baseline for the ICT4E2B Forum approach, where this large-based approach has been further extended with the “Forum” concept that should continuously involve stakeholders in roadmap development. Furthermore it is worth to notice that 4 of the 6 partners of this project are members of E2BA, which allows the project to exploit the already mentioned multiplying effect of the association.

During EeB Roadmap preparation, an in-depth analysis of strategic research agendas, implementation plans and relevant R&D position papers from running European Technology Platforms (ETPs) and Joint Technology Initiatives (JTIs) was performed in parallel. This was duly confronted with other relevant European initiatives, such as the roadmaps of the industrial initiatives or the SETIS information system within the SET Plan. This allowed the building up of a taxonomy, which globally maps the European R&D priorities landscape, relevant to energy-efficient buildings. In case of ICT4E2B Forum the main input for the taxonomy has been the one delivered by REEB that has been further investigate and refined during the project, nevertheless it is worth to notice that the main thematic areas of ICT4E2B and REEB can be easily resembled in EeB PPP taxonomy.

The two parallel exercises performed by E2BA demonstrated a powerful synergy and have been very important in the identification of research priorities. More than 1700 inputs from relevant European initiatives of potential interest for energy-efficient buildings have been identified. The inputs collected from the E2BA members have been compared with research priorities identified from the analysis of the strategic research agendas, implementation plans and relevant R&D position papers, as a crosscheck that relevant research challenges for the sector were not missed. An in-depth analysis and clustering exercise has been performed on the research gaps and challenges gathered during this initial phase. Five major areas have been identified, each grouping several research challenges (see figure below).

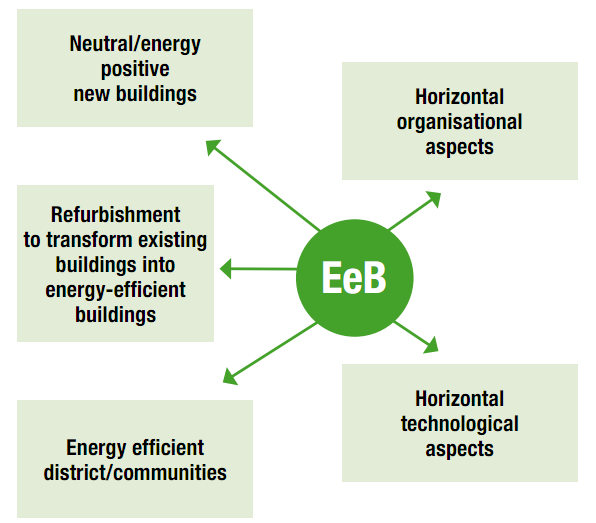


Figure 2: EeB PPP Multi-annual Roadmap

All the five areas can be influenced by development of ad-hoc ICT,which could effectively contribute to the advancement of the energy-efficient built environment. At the same time with the development process of the new Framework Programme (FP), E2BA have already started two relevant road-mapping exercises that can take relevant contribution from the outcomes of ICT4E2B Forum:

1. Update of the PPP Multi-annual Roadmap, whose first version was released in 2010. E2BA is going to accurately reconsider the different prioritised challenges under the 5 main areas. The document will present E2BA Vision, priorities and targets for future research in the field of energy efficiency for buildings and district. Indeed the overarching goal of E2BA is to support both Climate and Energy policies set at European level. This requires making building owners ready to invest into a built environment having lower energy demand and lower GHG emission footprints over their whole life cycle, thanks to “idiot proof” user interfaces that prevent building users from misbehaviors leading to energy overconsumption. This update work will be influenced by the activities performed by running project and by the new priorities underlined by stakeholders. ICT4E2B Forum will be able to contribute by the detailed analysis of running activities performed in D1.3, while prioritisation performed in D2.2 will allow giving the perspective of ICT4E2B stakeholders.
2. Development of New Long Term Strategic Roadmap, to really adapt the E2BA long term strategy at the general socio-economic evolution and to the specific need of the upcoming Framework Programme, it seems necessary the development of new long term strategic roadmap with a clear perspective of what the field of energy-efficient buildings can achieve at different timescale. Indeed several meetings have been organized in order to gather information from the different stakeholders involved in the value chain of construction for energy efficiency. ICT4E2B Forum contributed in identifying research priorities and future development for the EeB Multiannual roadmap in almost all of the steps of the value chain from Design to End of Life. Indeed one of the main idea is to consider a practice oriented integration of ICTs to support construction sector processes. This priority is widely supported by the E2BA/ECTP community and this will require a strong involvement in fostering the development of integration technologies. Within this activity ICT4E2B Forum roadmap (D2.3 and D2.4) will be able to give a clear understanding of what are the vision, gaps and priorities and all ICT4E2B relevant challenges.

It is apparent that a strong link and a synergetic strategy is required among the initiatives that will lead to the preparation of both of the Roadmaps (ICT4E2B Forum and EeB PPP Multiannual).

# Vision

The following vision is slightly modified from the previous REEB project [1]:

ICT will contribute to the energy efficiency of buildings mainly via design tools, automation and control systems and decision support for various stakeholders.

* **Short term:**ICT enables the connectivity and interoperability of individual buildings and networks and is used to ensure that existing and new buildings meet the current and emerging requirements for energy efficiency defined in relation to the surrounding infrastructure and climate.
* **Medium term:** Design, production, retrofitting, operation, use and demolition are empowered and enabled by re-configuration, optimisation, and access to real-time information, decision support and interoperability with easy to use interfaces.
* **Long term:**ICT enables and supports new business models and processes driven by energy efficiency. Buildings have evolved from energy consumers to “prosumers” (producer + consumer).

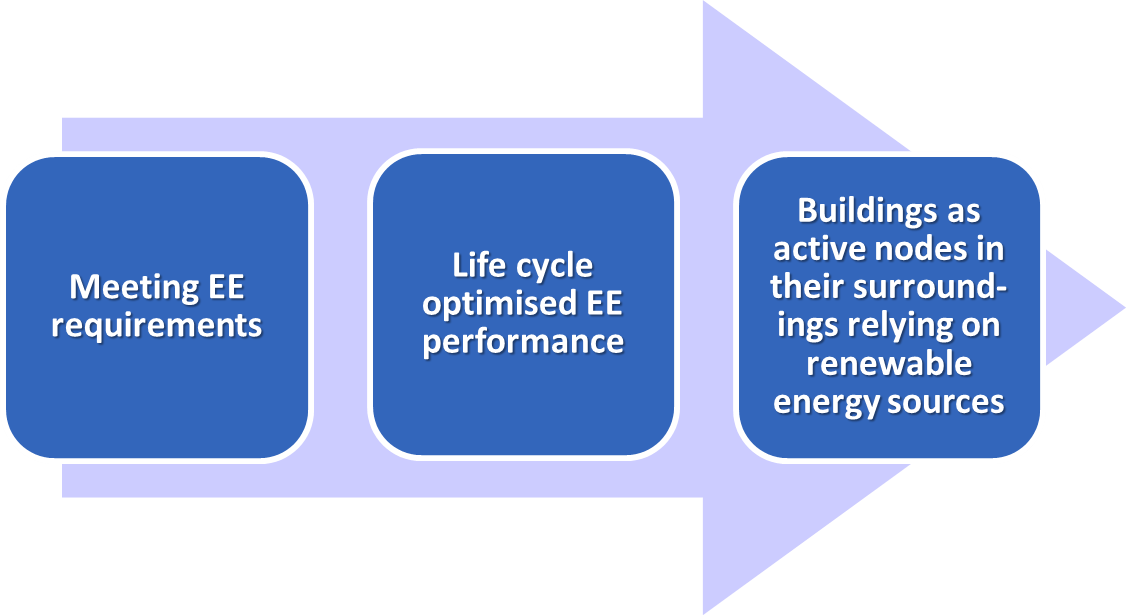


Figure 3: Updated vision for ICT enabled energy   
efficiency in short, medium and long term

An industrial transformations within the construction sector is envisaged through the role of ICT for energy efficiency in buildings as follows:

* Life cycle approach: Integrated design teams, using interoperable model-based tools and communication/collaboration platforms optimise the whole life performance of buildings.
* Smart buildings: Most buildings will be "smart" and control themselves maintaining the required and optimal performance and responding proactively to external conditions and user behaviour anticipating them, rather than reactively. Holistic operation of subsystems is supported by integrated system architectures, communication platforms, 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 re-usable 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.

# Updated Strategic Research Agenda (SRA)

## Tools for EE design and production management

### Vision

**BIM-CAD, Collaborative design environments, user interfaces**

The architects and engineers are provided with libraries of intelligent (parametric) objects that can adopt (design / configure) themselves in a specific context with essentially less human interference than today. Transformation of design process from computer assisted manual work into a knowledge based “industrialised” process.

Best-practiceswill be embedded in BIM models as reference design solutions where built-in “smart advisors” will analyse or simulate the evolving BIM during the design process presenting various EE indicators as optimal solutions associated to the current design activity, instrumentingEE performance estimation as coherent feature of preliminary design phase.

Intelligent product catalogueswith auto-design BIM software are available to choose producer independent materials from embedded EE-product catalogues.Intelligent (parametric) objects in libraries can adopt (design / configure) themselves in a specific context with essentially less human interference than today. There exists protection of the intellectual property rights (IPR)of design knowledge that is shared digitally with other organisations.

Semi-automatic generation of production plans by combining BIM with libraries of productions methods and resources (materials, components, machineryand suppliers) is available. Self-learning design system with embedded case-based learning is used.Integration of building and district level modelsinclude energy exchange between buildings, local generation, storage and grids.

**Model analysis and validation, 3D-Visualisation**

The decision making of owner/user is supported by exploiting virtual environments where simulation, visualisation, interaction and mixed reality with text, diagrams, 3D and comparison with EE indicators derived from BIM, will be used to evaluate entire life cycle cost of building supporting the interest of stakeholders.

Systems and service integration at all levels throughout the building life cycle enable collaboration of distributed teams.Versatile model analysis tools will be available for analyses and validation of BIMs, alerting users to take corrective actions e.g. with respect to coherency, EE and compliance to requirements and building codes.

Most commonly used building simulation tools will be fully interoperable with commercial design tools and BIM. Also full scale building simulation will take less amount of time where several alternative solutions can be studied rather quickly and easily.Test cases by comparing software tools in standardised reference cases will be used to develop validation/ certification process of tools.

Standardise performance indicators at European level will be available where they can be assessed based on standardised BIM and building energy management systems(BEMS) data which is available from various enterprise systems.

**EE Verification, performance based contractual practices:**

Project management interface will provide integrated context-oriented information for on-site and off-site construction management; implementation of ICT on remote construction projects will be commonly used for managing workflows and process flows.

Production will be managed through enhanced BIM-based tools with features to include output of optimised operations to improve energy efficiency. These include the logistics optimisation to reduce emissions and the purchasing of sustainable materials.

Quantifying tools for measuring EE and production management will be available with product database specifying the energy value of materials and logistics. There is real time collaboration between stakeholders for design, production management and building operation phase.

There are tools to specify the performance of the building and to verify it with respect to requirements. Monitoring is based on the real (future) building and analysis or simulation using BIM. Such tools will support performance-based contracts. The vision is to accept computer based analysis as contractually valid verification of EE.

### Key research topics

Following presents some of the identified research topics in four categories:

Design

* Development of libraries of best practices and reference design solutions
* Certification of tools
* Development of contractual and legal validity of BIM, and digital information in general, as the carrier of design information without the need for “documents” like text and drawings (~”BIM-PDF”)
* Development of tools supporting design and service configuration management

Production management

* Development of tools to support collaborative working environments, modelling, simulation, social media, visualisation, workflow management
* Development of BIM-based project management tools, performance simulation, e-procurement, intelligent e-catalogues, ICT standards
* Development of tools to optimise production EE as part of life cycle (e.g. on/off-site production, local procurement, waste management)
* Enhancement of service provider/facilitatorimplementation of user requirements, service solutions based on integrated information models

Modelling

* Modelling interactions (energy trading transactions) between buildings and smart electricity and heating/cooling grids
* Development of tools to model analysis and validation for EE. Two kinds of validation is required

1. Ontology e.g. check that different stakeholders/tools have the same definition of the needed information about e.g. windows
2. Instantiated data e.g. check if a specific building, based on its model, complies with requirements e.g. EE

* Development of tools to support modelling of user behaviour with respect to energy consumption for design phase
* Enhancement of current BIM models (IFC) with standardised EE attributes
* Development of information models for mobile technologies

Performance estimation

* Definition ofEE performance indicators and related assessment methods and tools
* Standardisation of performance indicators at European level in a way that they can be assessed based on standardised BIM and BEMS data which is available from various enterprise systems
* Development oftools to show overall performance of the building throughout life cycle and financial instrument to support stakeholders in evaluating the total cost and benefits
* Establishing estimated performance as contractually valid requirement and defining related verification methods
* Development of test cases for simulation software tools to support validation and certification
* Establishing virtual testing environment for Performance Estimation
* Development of performance verification tools /performance -driven process

### Drivers, barriers and impacts

General expectation today is short term, i.e. fulfilling the requirements at lowest possible cost. A trend for stakeholder group is needed towards a longer term strategy for life cycle optimised buildings.Industry might gain more control, but energy efficiency factor needs to become the part of core strategy of business changing business models. In the current scenario companies need to provide added value to clients (e.g.EE services), thus not only changing the business models but by having other business in parallel differentiated by brand.

Regulation for energy efficiency centres will enhance on the regulation, directives, building codes, building permissions etc. The importance of integration of renewable energy sources increases and advanced stakeholders will support integration of building life cycle in operation phase as a longer-termstrategy.

New applications will be driven by increasing EE awareness and new EE business models and services, and will mostly be enabled by integration of various functions/tools and improved communications between stakeholders.

As a barriers in the current scenario, for buildings to be energy efficient requires more efforts from the architects and designer where supporting tools for designing embeddedwith EEfeatures and simulations consumes excessive amount of time and resources. There is a need to enhance such tools in a way that more results for designing and evaluation purposes in less time and with resources can be realized. Following are the identified barriers:

* Lack of interoperability
* Stakeholder specific sub-optimisation and inability to integrate model based information between stake­holders supported by the current regulations (e.g. tendering procedures)
* Unresolved IPR of semantically rich infor­mation
* Un-availability of EE data about materials and products
* No systematic feedback from operation to design
* Lack of rewarding contract models that support holistic optimisation; Incompatibility of business incentives for design vs. whole life cycle performance. No systematic feedback from operation to design
* Commonly used design simulation tools are not 100% interoperable with design tools leading to duplication of work and also requireexcessive time for full scale building simulation
* Prevailing business modelsare focusing on delivery costs instead of value to client
* Inability to measure, verify and prove EE of buildings
* Inability to integrate model based information between stakeholders

Gained impacts are:

* Compliance at lowest cost
* EE services (performance based contracts providing incentives for both sides, participation of stakeholder group in life cycle optimisation of buildings)
* Life cycle optimised buildings
* Branding

### Roadmap

A preliminary roadmap is depicted in the table that follows.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | **From s-o-t-a to short term** | | **From short to medium term** | **From medium to long term** |  |
|  | **Drivers** | Increasing EE requirements from regulations and users. | | 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 vs. 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. |  |
|  | **Impacts** | Compliance at lowest cost. | | EE services.Life cycle optimised buildings. | Branding EE design and production services. |  |
| **State of the art** | | **Short term** | | **Medium term** | **Long term** | **Vision** |
| **Design:** Discipline-oriented analysis and configuration management tools. CAD 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.  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. | | 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:** Numerous 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. |

Roadmap 1: Tools for EE design and production management

## Intelligent control

### Vision

Full energy-efficiency benefit is harvested through collaborating subsystems and optimal predictive control balancing the trade-off between comfort and energy consumption, local production and storage. Buildings are collaborating on district and city level and building controls are automatically interacting with the smart grid in able to exploit maximum amount of renewable energy sources on-site and level the use to avoid peaks. The systems have self-diagnostics and provide a 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.

### Key research topics

To increase energy efficiency through intelligent control requiresresearch in several areas. Following presents some of the identified research topics in four categories:

Automation and control

* Enhancement of energy prediction models and tools
* Development of energy optimal coordination algorithms between applications such as HVAC, lighting, security, etc.
* Development of application of predictive controls considering weather forecast, demand response events and peak power constraints
* Generating optimal building controls from a Building Information Model (BIM)
* Development of real-time algorithms for energy-efficiency diagnosis
* Developing building controls responsive to smart-grid interactivity
* Enhancing optimal controls on district and city level
* Enhancing equipment manufacturers to provide dynamic models of their products enabling simulation
* Development of algorithms that learns tenant behaviour and derives optimal control decision based on this information.

Monitoring

* Decreasing production and deployment cost of basic communicating meters
* Increasing data collection while protecting the privacy of individuals
* Embedding more intelligence in sensors to perform local analysis
* Developing self-diagnosing equipment detecting suboptimal energy performance

Quality of service

* Development of better interoperability and reliability of the technologies and systems
* Enforcement of detection of problems
* Embedding self-diagnosis in sensors
* Using virtual reality for diagnosis and repair
* Including sensors and diagnostics in building materials

Wireless sensor networks

* Development of communication standards ensuring multi-vendor interoperability. In particular for wireless communication supporting battery-less low-power devices.
* Definition of standardised roles and services for sensors
* Development of automatically adapting network topology
* Establishment of cost-effective deployment procedures

### Drivers, barriers and impacts

The main driver for intelligent control is increased EE but also to produce economic savings through acting on dynamic energy prices and curtailment events. Another is the need to balance the energy flow between consumption, local production and storage within the building.

Potential barriers include:

* Lack of interoperability between different building systems, i.e. security and HVAC.
* The return on investment of a particular functionality can be hard to estimate accurately
* Lack of tools for easy deployment of advanced functionality
* Lack of global systematic approach for energy efficiency
* Security concerns
* Privacy concerns

The main impacts are

* Increased and sustained EE through active control and fault detection
* Buildings as active components able to interact with the smart grid

### Roadmap

A preliminary roadmap is depicted in the table that follows.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | **From s-o-t-a to short term** | **From short to medium term** | **From medium to long term** | |  |
|  | **Drivers** | Increasing EE requirements.  Dynamic energy prices. | Local production and storage of energy. | Regulations and standards for energy efficiency. | |  |
|  | **Barriers** | Focus is more on capital investment than operational cost and savings during the lifecycle.  ROI must be proven before investment decisions, which hindrances the launch of new products.  Lack of interoperability between actors. | Insufficient interoperability.  Security and privacy concerns | End-user acceptance. | |  |
|  | **Impacts** | Increased demand for a Building Management System (BMS). | Sustained energy efficiency. | Improved district energy management. | |  |
| **State of the art** | | **Short term** | **Medium term** | **Long term** | | **Vision** |
| **Automation and Control**: Standardised solutions for control. | | Coordinating algorithms between applications. | Predictive control considering weather forecast, make building controls responsive to smart-grid interactivity. | Generate optimal building controls from BIM, optimal controls on district and city level, equipment manufacturers provide dynamic models of their products enabling simulation. | | 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. |
| **Monitoring**: Monitoring as a standard component in a modern BMS and measurements used for building control stored in trend logs. | | Decrease production and deployment cost of basic communicating meters. | Increased data collection while protecting the privacy of individuals, embed more intelligence in sensors to perform local analysis. | Sensors are built in the fabric of the building. | |
| **Quality of service**: Basic self-diagnosis commonly available in automation control products. Large quantity of self-diagnosing functionality with associated alarms. | | Enforce that detected problems get attended, develop real-time algorithms for energy-efficiency diagnosis. | Embed self-diagnosis in sensors, self-diagnosing equipment detecting suboptimal energy performance. | Use of virtual reality for diagnosis and repair. | Inclusion of sensors and diagnostics in building materials |
| **Wireless sensor networks:** Wireless technologies for building automation available, but there’s a lack of interoperability between different vendors. | | Develop communication standards ensuring multi-vendor interoperability and supporting battery-less low-power devices, establish cost-effective deployment procedures. Develop gateways to common industrial protocols. | Define standardised roles and services for sensors, automatically adapting network topology. |  |

Roadmap 2: Intelligent control

## User awareness and decision support

### Vision

ICT supports understanding, capturing and formalising customer/client needs into requirements, conveying them to all stakeholders and validating compliances. The impact of ICT on EE is well understood thanks to the diffusion of model-based evidence. Standardised methods and indicators are available for decision-support to assess and benchmark the energy performance of districts, buildings, systems and components. Performance audits, labelling and continuous commissioning are supported by recorded data of real time performance.

Main roles of ICT in awareness and decision support are to:

* Provide information to users of buildings, owners, facilities managers, local authorities and urban planners about energy consumption
* Enable occupants to control devices in buildings in order to decrease consumption
* Make occupants aware on how their activities will influence energy use from short and long term perspectives
* Motivate and support behaviour changes by highlighting other factors that affect energy usage (like demographics, family composition)

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. It is possible to gather information about many environmental factors (temperature, humidity, CO2 concentration, solar radiations, etc.) and predict possible energy use.

As users in the SmartGrid era will be able to not only consume but also produce energy (hence called prosumers), and interact with the smart buildings, the dynamics and complexity of the system increases. Being able to use information and communication technologies may provide an insight on the prosumer current and future activities that is not possible in the conventional grid. As the future energy monitoring and management system will be in close cooperation with the enterprise systems, enterprise services will integrate information coming from highly distributed smart metering points in near real-time, process it, and take appropriate decisions.

The decision making process can consider prosumer-specific behavioral information either measured, assumed or explicitly provided by the prosumer. This will give rise to a new generation of applications that depend on ”realworld” services which constantly hold actualized data as they are generated. Furthermore the integration of potential future behavior of the prosumer may enable better correlation and analytics. This crowdsourcing of information via bidirectional mobile communication with the prosumer, which relates to his infrastructure, planned activities and current context may provide us with not only better understanding but also future knowledge that could be considered in future energy management and decision support systems.

### Key research topics

**Performance Management**

* Implementation of multi-criteria performance monitoring analysis and optimisation by using the information collected during the monitoring, and take corrective/optimisation measures to improve the energy efficiency while maintaining operation goals.
* Forecasting of energy demand by taking into account not only the current building operation conditions but also its expected evolution, which depends on external entities such as the weather forecast and the scheduled building usage profile.
* Dynamic integration of smart building users, their needs while in parallel striving towards quality of service and energy efficiency.
* Development of a multi-dimensional visualisation system of parameters of building operations and data sharing from technical systems;
* Definition of performance metrics and policy marker at European level.
* 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) as well as benchmarking tools that exploits comprehensive and transferable indicators easily understood by urban planners to find the best integrated building concept, and user to find the best way to control their buildings. With the momentum of green design, new technologies and applications are continuously being developed to assist in sustainable living. A large percentage of energy is consumed in buildings, majorly impacting our individual carbon footprint. By monitoring buildings’ energy consumption in real time with a web or mobile application users can pinpoint vampire devices, times of high or low consumption, and wasteful patterns of energy use.

**Visualisation of energy use**

* Development of new human-machine interfaces (HMI) and smart energy meters incorporated into BMS is important to provide real-time information on energy consumption in building.
* Web & mobile device accessible “energy account” could provide users a usable device to have real-time control on energy consumption and an intuitive way to understand how to modify their daily behaviour that affects energy consumption.
* Improvement of integrated energy visualisation tool in order to provide users a detailed vision of their individual carbon footprint considering the overall of daily activities they performed is needed. However, the development of common rules as a base for readable reports on energy consumption to end-users is needed.
* Consider the end-user needs (cultural context, comfort, user’s behaviour, etc.), exploiting intelligent system for data management. This could be done with the help of new cross-domain stakeholders such as sociologists.
* Identifying of the level of individual knowledge that each user (such as occupant, inhabitant, and building’s owner) must have about the buildings in which he lives or works in. This kind of knowledge should be referred to the followings subjects:
  + Geographical information: the place where the building is built, in order to be able to identify the features of the building itself, like orientation to the sun, wind exposure and so on, but also information the external environment
  + The inner comforts: for instance the electric equipment, which are installed in the building, that increase the daily level of well-being for users living or working in the building and are directly or indirectly used by end user.

**Behavioural change**

Creation of paperless on-line solutions to easily display up-to-date drawings and other construction related materials on site:

* Showing evidence and demonstrate the comparison of investment and operational costswith the achieved energy savings and energy efficiency improvement.
* Development of intelligent and usable e-learning system that allows changing 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.Theuser-friendly websitesbecome the “gym” where users, easily from their house, could learn the merits and methods of energy conservation in order to reduce energy consumption and save money.
* Development of tools for comparison at neighbourhood level or with similar unities, e.g. family composition and user density within the building.
* Development of on-line tools to verify the adequacy and compliance with the Energy Performance of Buildings Directive (EPBD).
* Development of ICT solutions should enable “social sharing” since “social pressure” is one of the best means of getting people involved in changing their behaviour.
* Intuitive mobile applications for smart phones will help users to quickly understand their usage habits by clearly identifying total consumption as well as individual device consumption. This kind of applications and devices installed in buildings can help in obtaining valuable information. Users will be able to turn on electrical appliance in the most appropriate moment to reduce energy or when the net will be less charged using their smart phones being away from home or using television for example.

### Drivers, barriers and impacts

The main drivers to increase users to get aware of energy consumption and efficiency from short and long term perspectives are represented by the:

* Identification of individual knowledge
* Lack of standardised data formats and models that can enable rapid integration in applications
* Enable user-specific information assessment and advanced energy management
* Reduction of technological equipment cost and energy consumption.
* Identification of European standards and common metrics

In addition, it is important to train occupants to understand that they are a key component in the building and of any EE strategy.

Any technology that hopes to affect energy use, especially by individuals, must take into account the “**motivation of the users**”, i.e.

* What does each individual really care about?
* What motivates him or her?
* What lifestyle do they have / would they like to have?
* What are the person’s desires?
* Is it to have fun?
* To be comfortable?
* To make a difference?
* To become more integrated into the community?

Therefore, the best technology would tap into a person’s motivations, lifestyle and habits would enable him/her to better understand and be able to make aspirational, fun, ‘desirable’ lifestyle choices that would have the effect of reducing energy. Technologies are progressing with increasing velocity and the knowledge of people, who must make decisions and act upon to meet energy reduction targets, is easily lagging behind.

Furthermore “**social pressure**” is one of the best means of getting people involved in changing behaviour, and that technology that enables EE in the next 10 years or sooner would need to enable social sharing.

As a key barrier people are usually not willing to adopt new things especially if it requires a change in their behaviour. They have had gained habits through the years and it is not easy to convince them to change. Otherwise, people are reacting when they are dissatisfied with a situation. So it is not about a lack of willingness, but about a lack of triggers: this clearly indicates that one of the needs for large spreading of ICT for energy efficiency is thus identify the right direction to make people reacting. Therefore presented solutions have to be user friendly as much as possible as well as relevant and effective.

Designers, architects and civil engineers can use different software tools supporting their decisions, however mostly they are not operating with the same format standard. The **identification of European standards and common metrics is** fundamental to have regulation that allow to obtain a reference metric that can be used across different European Countries. There is a general trend to make uniform data standards, but also special engine software tools available (like FME - Feature Manipulation Engine) that are able to transform a format into another. Moreover, from the standardisation point of view it would be useful to have a complete list with energy features for each material product for instance in the field of construction.

From the impact point of view the users and owners of buildings will be the main beneficiaries as they will be empowered to make informed decisions about the building and its use. Although technology is only one of the available tools that could be used to achieve energy saving and that in order to achieve maximum impact, ICTs would need to be combined with non-ICT tools in a suite of energy efficiency measures available to users.

### Roadmap

The following figure illustrates the roadmap for intelligent and integrated control. It covers the current state-of-the-art and research priorities in the short, medium, and long term.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **From s-o-t-a to short term** | | **From short to medium term** | | **From medium to long term** | |  | |
| **Drivers** | Cost reductions | | user-driven demand for applications and services | | Social Pressure | |  | |
| **Barriers** | Lack of data related to energy use profiles Concerns over privacy and security | | Lack of European standards and common metrics  Lack of multi-disciplinary approaches/solutions to EE | | People’s habits, lack of integration in social applications | |  | |
| **Impacts** | ICT is be combined with non-ICT tools in line with energy efficiency measures 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. | |  | |
| **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 that are capable of balancing the levels of automation and individual choice, performance database.  Interoperability between BMS and real-time diagnostics system, for comparing estimated (designed) and observed (actual) performance | | Parameterisation of the intelligent BMS by using specific energy based knowledge management system.  Integration of personal energy use between different building contexts, privacy and security | | Heterogeneity of the system, definition of common standards and metrics at European level.  Combination of ICT tools with non-ICT tools for obtaining an effective assessment of the energy consumption. | | There are smart, fun and easy to use and effective energy management tools, which exploit real time energy consumption/production information and help the different stakeholders to achieve their tasks while being energy efficient at building level.  Visualisation of energy use anytime anywhere with management capabilities and integration in multi-domain applications and services. Energy analytics and decision support systems that provide useful suggestions to change habits to decrease energy consumption and costs. | |
| **Visualisation of energy use** | | Attractive and understandable energy visualisation display, identification of the level of individual knowledge that each user must have about the buildings in which he lives or works in. | | Organise training sessions and e-learning websites for user involvement, integration of building services with user’s needs and interactions. | | Exploit “social pressure” as a driver for motivating users on energy efficiency themes, integrate with social applications and services. | |
| **Behavioural change:** Technologies are available to be used improving the level of user awareness. | | Real-time internet accessibility to control building energy-related processes, development of energy bank database. | | Increasing involvement of building users and owner on the use of BMS.  Reduce technological costs and learning curve for end users. | | Daily energy consumption plan act to follow the scheduled activities planned by the users and to support end users energy decision during the whole building life | |

Roadmap 3: User awareness and decision support

## Energy management and trading

### Vision

It has been shown that value is created when interactions among people, businesses and generally entities exist. For these interactions to happen, networks are formed that operate with their own rules over an infrastructure. The smart grid enabled city is an emerging complex system of systems where different stakeholders will have to strive towards achieving their goals while interacting with eachother. At parts of the city such as the districts, the energy signature and efforts towards its better energy efficiency will heavily depend on the utilization of availability and optimal usage of the local resources. The latter may be very dynamic and depend on several complex conditions such as weather, prosumer behavioural patterns, business interactions etc.

Energy Management and Trading are seen as key issues in the emerging future energy infrastructure. An energy market is one possible direction towards easingthe interactions among all smartgrid stakeholders withinthe scope of a smart city. It is not clear how thesemarkets will operate and what the minimum requirements are in order to have them functional and beneficial fortheir participants. Buildings could play a key role in energy markets as they are no longer passive energy consumers but active prosumers and by adjusting their energy flexibility can take part also in energy markets. 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 smart city entities e.g. buildings, transportation system, public lighting, etc.).

In this context future smart buildings are expected to play a pivotal role. Within the buildings themselves, intelligent devices are monitoring and actuating autonomously its behaviour in order to achieve the desired functionality. Users are now able to interact with the building and configure it to fulfil their needs, event temporarily; this is possible only because a new generation of energy services enable this kind of interaction. Several optimisations take place at local and building wide level considering the internal as well as external conditions.

Buildings are no longer striving towards energy optimisation only at building-wide level but also consider district or even smart citywide constraints. As such they may collaborate with nearby buildings in order to achieve energy efficiency. Additionally they collaborate within a smart city infrastructure e.g. the transportation system and use their resources (internal operations, electric vehicles on their parking place, etc.) to assist the optimal electricity network operation e.g. acting 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, intelligently plan their energy behaviour and even provide new revenue sources to their owners by adjusting flexibly 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.

### Key research topics

From the research perspective there are several issues that need to be investigated. Some of these include:

* Migration towards open and fully open and service-based infrastructures
* Energy storage and flexible management of it
* Adoption of collaboration tools for open cross-industry information exchange
* Enhancement of energy prediction models and tools
* Standardisation
* Development of energy optimisation and control models and tools
* Development of real-time analytics
* Development of models and methods for assessment and comparison of energy footprint during the whole lifecycle of processes
* Development of tools for data security, privacy and trust management
* Development of Internet based energy services for smart buildings
* Integration with online energy marketplaces
* Easy integration of alternative energy resources and Demand-Response management
* Development of tools for the assessment of approaches during their whole lifecycle including cost, environment impact, maintenance etc.

### Drivers, barriers and impacts

There are several stakeholders that will directly or indirectly impose 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 and Policy/Regulation reasons imposed at European wide level may also push towards this direction.

Potential barriers include:

* Lack of awareness on innovation for energy management as part of an ecosystem
* Lack of demonstrating clearly the benefits in real-world lighthouse projects
* Lack of open standardised approaches for energy data monitoring and assessment
* Lack of policies and incentives at national and European wide level
* Inadequate workforce skills and training
* Lack of ICT tools for enabling interaction of all stakeholders
* Lack of business adaption and availability of value added services
* Security concerns
* Privacy concerns
* Failure to anticipate the lifecycle management i.e. from cradle to gravefor the maintenance of large scale systems
* Focus on standalone solutions and goals and failure to consider collaboration at all layers.

Significant economic, social and innovation impact may be achieved.We see three distinct directions relevant to Energy management and trading:

* Building Energy Management: Here significant impact could be achieved, tackling energy efficiency and with the first results already available in the short-term.
* District Energy Management: Significant impact could be achieved in the mid and long term that could lead to optimal energy management at district and smart city level.
* Smart Grid and the Building Environment: Integration with the Smart Grid and optimal consideration of the Building environment and advances in other sectors e.g. construction could both lead to high impact and act as an enabler for energy efficiency.

### Roadmap

A roadmap is depicted in the table that follows.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **From s-o-t-a to short term** | **From short to medium term** | **From medium to long term** |  |
|  | **Drivers** | Stakeholder and technology driven | Economic reasons e.g. increased energy prices, user-demand | Policy/Regulation at EU level; realisation of an EU-wide open energy market |  |
|  | **Barriers** | Technology, market, social barriers | Acceptance of ICT tools for enabling stakeholders; integration in business | Business adaption and availability of value added and self-sustained services |  |
|  | **Impacts** | Significant impact in BEMS | Significant impact in District Energy Management | Integration with Smart Grid and the Building Environment at smart city level |  |
| **State of the art** | | **Short term** | **Medium term** | **Long term** | **Vision** |
| **Building Energy Manage­ment:**Isolated solutions(not interoperable)availabledealing with energy management in buildings. Limited number of smart appliances available. | | Smart metering, adoption of basic 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. Analytics offer better view on building processes and better management can be achieved. | Provision of complex user services, real-time fully automated energy management and adjustment to dynamic conditions and user needs, collaboration with other buildings and systems. | Flexible building energy management adjustable to user’s as well as external needs.  Integration of intelligent devices and accurate monitoring &forecasting by context information integration.  Interoperable energy management solutions beyond standalone systems/buildings.  Real-time energy management depending on Key Performance Indicators (e.g. cost, efficiency, etc.).  Participation in Real-time Demand-Response approaches – new revenue generation.  Buildings collaborate with their users and the local district for energy efficiency.  Collaboration of buildings with each-other, smart city infrastructure and participation in energy markets  Towards autonomic smart buildings with self-management, self-monitoring, self-healing and self-optimization. |
| **District Energy Management:** Some District Energy Monitoring solutions are available (not real-time), hardly any energy services for the citizens | | Energy monitoring at district level, opening of functionalities and provision of basic energy services. | District-wide Energy services for end-users, deployment of district-wide energy management (DR), citizen energy services and best practices, privacy and security assessment tools. | Real-time adjustment and optimisation of district’s energy management to conform to KPIs, full integration with all parts of the smart city (including public infrastructure, transportation etc.), energy simulation and detailed modelling 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, sharing of information. | User participation on district energy marketplaces, value added energy business services, best practices and models | Real-time demand-response solutions, participation of prosumers to groups and free energy trade, automated Intelligent Energy management for virtual groups of buildings/users, market-driven energy services. |

Roadmap 4: Energy management and trading

## Integration technologies

### Vision

The dynamic nature of design projects requires parallel processes, smooth workflow and tight control. There are applications to give support to all these needs and allowing different profiles of experts work together in a project with no difficulty related to coordination of processes and the shared control of the entire project. These kinds of applications offer smart workflows that are synchronised automatically depending on the status of the project without any help.

Embedded diagnostics methods, which are capable of running on local controller devices, 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 consider future energy consumption and based on that adjust the consumption curve by shifting or curtailing some of the loads. In case of system optimisation, the control strategy uses the information about the operation states, loads, weather conditions, tariffs, and equipment characteristics.

Data models and real-time communication protocols are standardised in order to allow all the stakeholders to develop their devices without problems at the moment to plug them and make them to work together. Devices from different producers arein use at the moment when plugging them, because all the devices inside and outside the buildings share the same protocols. Other domains protocols and standards are integrated as needs and applications of buildings will increase.

The information from different stakeholders is shared between them using inter-organisational knowledge platforms,where the information is organised by term and which offers an easy way to be consulted.

### Key research topics

Nowadays, in thedesign and construction process of abuilding, very differentapproachesareneeded, which leads to engagein the process different kindof professionalswithin their respectiveroleintheproject. Taking it into account and also the increasing complexity of the buildings in order to improve their efficiency, leads to a very high demand of ICT tools to achieve the objectives:

* A collaboration tool between all the stakeholders involved in the project in order to interact between them in the building life cycle.
* Better implementation of building lifecycle by changing the point of view regarding the importance of its energy costs.
* New embedded devices for monitoring and control the energy consumption in the buildings and in a lower level, taking into account each flat/office that compounds the building.
* Better tools to share and generate the knowledge between all the stakeholders involved (e.g. cloud technology).
* Combination of human networks, social capital, intellectual capital, and technology assets, facilitated by a culture of change.

The technological development that is requested to satisfy these demands has been structured in the following RTD topics:

* Process integration: focused in the development of reliable and useful tools in relation with collaboration and business work flows. In fact, it is one of the most interesting and key areas of research in order to end up with a tool capable of make efficient the interaction between all the roles involved in the projects.
* System integration: related with integration platforms and services supported, SOA, Middleware, Development methods and tools as Integrated design environments (IDE), embedded devices for control and monitoring of consumption, data modelling methods, Plug&Play. Identifying and understanding the borders of systems or between stakeholders is essential.
* Interoperability and standards: related with research areas involving data models and real time (in-side and out-side building) communication protocols. Rapid development of coherent standards for interoperability is needed. These standards should contemplate future systems and the broader range of applications that are being envisaged now. Moreover, improved interoperability must therefore be a core element of all future initiatives.
* Knowledge sharing: management of the access to knowledge using a platform with repositories, forums etc. with a user profile to split the users depending on their role and area of expertise. Also including data mining and semantic search.
* Network management functions: these are used in every control solution to design, configure, commission and install devices. Often network management functions appear invisible or operate automatically in the background during system/device configuration.

### Drivers, barriers and impacts

One driver to be taken into account that enhance the technological changes in relation with ICT for energy efficiency buildings is the social awareness about the problem of the Climatic Change and its relation with the building’s energy consumption. On the other site, it’s necessary to consider the presence of internet in most of homes and offices that gives more technological options to develop embedded software and devices to balance the consumption and the generation of energy in buildings as well as the real-time monitoring and control.New protocols like IPv6 will ease the communication and integration between different devices inside and outside the buildings as well as the implementation of the Smart Grid concept.

The main barrier at this point is the lack of knowledge about the importance of the adoption of a building life cycle in relation with energy cost. As we know, a lot of stakeholders take part in the building life cycle and usually most of them are not big companies. Therefore most of them are focused in their role on it and it’s difficult to find any stakeholder that can lead the adoption of it overall the whole process.

The difficulty that represents to adapt the existing building to the new approaches of energy efficiency in buildings is another barrier at this point. It’s clear that the installation needs to be automated and more complex and no always it is possible without a big investment.

Expected benefits and business opportunities to key can be summarised in the following ones:

* Better knowledge about building life cycle energy performance and the importance of its adoption regarding reduction in building project execution times and costs and higher quality of the buildings
* Implementation of the smart-grid concept. Higher integration of buildings in the energy networks will allows exploiting the building’s energy generation and storage capabilities and their associated equipment, as future electric cars.
* New business opportunities for ICT, energy and building sectors.
* Higher sustainability with lower resource’s consumption (i.e. travel, energy, etc.) via changes to the way we work.
* Achieve a standardisation regarding communications and protocols to ease the interoperability and the communication among different devices.
* Share of knowledge among all the stakeholders involved in energy efficiency.

### Roadmap

The following figure depicts the Roadm

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | |  | **From s-o-t-a to short term** | | **From short to medium term** | **From medium to long term** |  |
|  | **Drivers** | | Increase citizen awareness on EEB. | | costs savings benefits | Increase demand for energy consumption prediction. |  |
|  | **Barriers** | | Lack of knowledge about building lifecycle energy management and difficulty to adapt new technological solutions to existing buildings. | | Too much property protocols and communications standards coexisting in the market.. | Access to the knowledge generated in all the fields related to energy efficiency in buildings. |  |
|  | **Impacts** | | New business opportunities for ICT, energy and building sectors. Change of mentality regarding the importance of EEB. Better implementation of building lifecycle. | | Achieve a standardisation regarding communications and protocols to ease the interoperability and the communication among different devices. Implementation of smart grids. | Share of knowledge among all the stakeholders involved in energy efficiency.New algorithms to plan and forecast the consumption in buildings. |  |
| **State of the art** | | | | **Short term** | **Medium term** | **Long term** | **Vision** |
| **Process inte­gra­tion:** Rude appli­ca­tions to integrate different roles in a project. | | | | Improvement of the rude applications existing in the market. | Centralized application able to control parallel processes done by different kinds of experts works in a project. | Development of smart common workflows. | New applications to support parallel processes, smooth and smart workflow, and tight control allowing different kind of experts work together.  Early detection of anomalous energy consumption and/or malfunction of networked devices by using embedded diagnostics methods.  Cost reduction for installing EE devices and reduction of problem interoperability among EE devices by using standardised data models and real-time communication protocols.  Definition of a “one shop point” platform that collects information coming from construction, energy and ICT fields and allows the sharing among stakeholders from these fields. |
| **System integration:** Coexistence of various communi­cation protocols and devices | | | | Systems integration from building level to neighbourhood level. | Networked Embedded software to devices are needed to control the consumption of buildings using diagnostics methods. | Systems to predict future consumptions and plan them are also a wide field to be investigated. |
| **Interoperability and standards:**Non inter­operability among devices and non-complete standards | | | | Agreement on the protocols and communications that fit better with the needs of the vendors and the existing devices. | Advancement of technology standards development and general adoption by most of the vendors. | All the devices inside and outside the buildings will share the same protocols. |
| **Knowledge sha­ring:** Different allo­cations for know­ledge share and difficulty to find it. | | | | Use of common forums and collaboration spaces to share the knowledge. | Development of a knowledge sharing platform among construction, energy and ICT stakeholders. | Improvement of seek methods in the common platform to allow a good access to the information related to EEB. |

Roadmap 5: Integration technologies

# Implementation action plan

In the REEB project [1], using the roadmap as a foundation, a call for research topics/ideas was launched to different stakeholders to solicit RTD topics supporting realisation of the roadmap. Altogether 63 topics/ideas were received covering all of the 5 main categories.

The ICT 4 E2B Forum applied a slightly different approach: Based on the SRA (section 4) the necessary actions by different stakeholders were identified.



Figure 4: Template for identifying information for   
the implementation action plan based on the SRA

## Integrated design

**Technical scope**

The life time 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 life time. 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.

**Classification**

1.1 Design; 1.2 Production management; 1.3 Modelling; 1.4 Performance estimation; 5.1 Process integration; 5.2 System integration; 5.4 Interoperability & standards.

**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 e.g. 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 which 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 impacts**

Integrated design has direct impacts on the design process itself as well as on the subsequent life cycle stages which 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 impacts of various design options and generally about the impacts 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 andto 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. Activate the construction design sector to adopt new technologies and collaborative business models.

*Construction sectorcompanies 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 of (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 interactingin 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 contractssuitable to temporary project teams in the construction sector. Develop 3rd party trust services for information sharing and archival.

*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 environements. 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 standardised performance metrics (EE indicators and validation methods) based on information that is available from current and emerging ICT systems.

## 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 asfor 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.

**Classification**

1.1 Design; 5.3 Knowledge sharing; 5.4 Interoperability & standards.

**Target outcomes**

* Catalogues with semantic information of materials, components and re-configurable 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 impacts**

* 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:*Expectapplication 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, parametrics and configuration management.
* *Energy sector:* Suggest information to be provided about local generation and storage facilities.
* *Knowledge providers:* Train/educate construction professionalson industrialised construction methods, mass-customisation and configuration design.
* *End-users:*Require comprehensive information about buildings, their subsystems and components.
* *Standardisation bodies:*Continued development ofICT standards for product information, regarding e.g. energy aspects (same also in 5.3), and metadata for catalogue items.

## Data models

**Technical scope**

Achieving energy efficiency requires holistic management of information from many stakeholders over the product (building) life time. 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.

**Classification**

1.1 Design; 5.4 Interoperability & standards.

**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 standardized 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 alreadylaunched activities in this area are foreseen to remain necessary in the long term.

**Expected impacts**

* 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 developmentof standards for product information regarding e.g. energy aspects (same also in 5.2).

## 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 like: 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.

**Classification**

1.1 Design; 5.3 Knowledge sharing; 5.4 Interoperability & standards.

**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 impacts, 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 management. 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 impacts**

* 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 he 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.

## Visualization of Energy Use

**Technical scope**

Definition of new interactive Graphical User Interfaces exploiting the new types of mobile devices such as smart phones and tablets.Availability of broadband internet connection wherever the user is located.

**Classification**

1.1 Design; 2.2 Monitoring; 3.2 Visualization of energy use; 5.1 Process integration.

**Target outcomes**

* Innovative and easy to use attractive interfaces and mobile applications to visualize 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 in.
* New IT solutions and embedded sensors will come from other field of use as pervasive technologies that will be user centric.

**Expected impacts**

Energy consumption visualization 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 visualization of end-user private energy data.
* *ICT sector:* Information is the key issue in supporting decisions and creating awareness. ICT operator will have a twofold role:
  + develop intuitive and easy to use user interfaces for visualization of energy consumption
  + collaborate with energy and public sector to the dissemination and communication of the potentialities of the new visualization tools to general public
* *Energy sector:* To provide incentives to their customers to facilitate the installation of energy visualization displays in the buildings.
* *Knowledge providers:* Organization of training sessions and development of e-learning websites to disseminate the advantages related to new visualization energy tools to final users.
* *End-users:*To be stimulated by the new visualization tool to reduce the energy consumption and change their behaviour towards better energy efficiency.
* *Standardisation bodies:*Spreading awareness providing specific guidelines particularly those that affects data security protocols to guarantee the protection of user private energy data during the visualization procedure

## 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.

**Classification**

1.1 Design; 1.4 Performance Estimation; 2.2 Monitoring; 3.3 Behavioural change; 5.1 Process integration

**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 impacts**

* 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-wide, regional, national and international level.
* *E2BA:* Promote the uses a European observatory on energy performance involving a European wide database.
* *Construction sector companies and organisations:* Guarantee of measured energy performancesto meet pre-set contractual values used as benchmark. Energy performance management achieves an high level of comfort and health (thermal comfort, acoustics, indoor air quality and accessibility in particular).
* *ICT sector:* To 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-user.
* *Knowledge providers:* To promote the use of performance management tools among designers, engineers, architects, urban planners. To 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:*To introduce harmonised European standards that allow to obtain a reference metric to be used across different European Countries. To make a complete list with energy features for each material and product, for instance in the field of construction.

## Behavioural Change

**Technical scope**

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

**Classification**

1.4 Performance Estimation; 2.2 Monitoring; 3.1 Performance Management; 3.2 Visualization of energy use; 5.1 Process integration

**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.
* The user-friendly websites become the “gym” where users, easily from their house, could 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 impacts**

* 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 (like demographics, family composition).

**Suggested roles of stakeholders in implementation**

*Public sector, building clients:*To create a legislation and incentives to promote the use of behavioural changes tools among building owners and residents to decrease the energy consumption. To 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 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:* To 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 currently are 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, 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:*Spreading awareness and acceptance on the necessary changes, providing specific guidelines, particularly those that affects lifestyles and behavior.

## Real-time Analytics on Energy Data

**Technical scope**

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

**Classification**

1.2 Production management, 2.2 Monitoring, 2.4 Wireless sensor networks, 3.1 Performance management, 3.2 Visualisation of energy use, 4.1 Building Energy Management, 4.2 District energy management, 4.3 Smart grids and the built environment, 5.1 Process integration, 5.2 System integration, 5.3 Knowledge sharing

**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 impacts**

* 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 potentially 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 decisions, analysis of data for the specific optimal case in their line of 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 in their tasks.
* *End-users:*Integration of results in their everyday life. New applications with insights on their own infrastructure.
* *Standardisation bodies:*Develop/enhance standards for interoperable and efficient information exchange and processing.

## 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 as well as basic services and applications that will enable DR and local market electricity trading.

**Classification**

2.2 Monitoring, 3.1 Performance management, 4.1 Building Energy Management, 4.2 District energy management, 4.3 Smart grids and the built environment, 5.1 Process integration

**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.Source [11]
* New approaches in interacting with the building’s users and consider their tasks/schedule (e.g. via their calendar) for the building-wide energy planning.

**Expected impacts**

* 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-wide 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 (i) communicate their state, (ii) adjust their state based on internal and external interactions (e.g. with a market, other buildings, energy efficiency guidelines etc.
* *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 on their own infrastructure.
* *Standardisation bodies:*Interact with the buildings and share information so that both can benefit from energy efficiency approaches.

## 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 minimize computational effort for optimization and tuning for a specific building. Research efforts are needed to find efficient model formats and to validate them using real-world data. This would support a systematic approach to energy efficiency.

**Classification**

1.3 Modelling; 2.1 Automation & control; 3.1 Performance management; 4.1 Building Energy Management; 4.3 Smart grids and the built environment

**Target outcomes**

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

**Expected impacts**

* Ability of buildings to rapidly balance energy flow between consumption, storage and local production.
* Buildings as active componentsin 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, which this technology is a core component for.
* *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 optimizations.
* *Energy sector:* Promote local production and storage of energy in buildings. Local production emphasizes the need of balancing energy flow, which this technology is a core component for.

## 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. All these devices monitored through the building energy management should be essential in the visualisation of energy use by end user and allow them to make decisions regarding this information.

The results from the EU research project e-Diana [12] (Embedded Systems for Energy Efficient Buildings) showed that is possible to improve energy efficiency and optimize building energy consumption by 25%, providing real-time measurement, integration and control by raising the awareness of the user about his household appliance energy consumption.

**Classification**

2.2 Monitoring, 2.4 Wireless sensor networks, 3.1 Visualisation of energy use, 4.1 Building Energy Management, 5.2 System integration

**Target outcomes**

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

**Expected impacts**

* Using this information, end users will be aware of consumption of each device taking it into account to reduce it.
* Reductions in the bill’s price by selecting the hours with lower price to switch on devices with more consumption.

**Suggested roles of stakeholders in implementation**

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

* *E2BA:* A better Efficient Energy Consumption control should be added on the section “ 2.1.6 Performance monitoring and management” for 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 hours.
* *End-users:*Be aware of this new information and use it to take decisions regarding energy consumption.

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

## Energy brokerage among end-users

**Technical scope**

Within the introduction of the capability to generate renewable energies in buildings, they are able to generate their own energy and in some cases they cannot consume all the energy they generate in each moment and in other situations they need more energy than they can produce. It is important to take into account these points and supply energy brokerage technologies to new buildings.

The EU research Project Encourage [13] 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 possible use of the electricity produced locally in their premises.

**Classification**

5.2 System integration, 4.2 District energy management 4.3 Smart grid and building environment, 2.2 Monitoring,

**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 external world, including other buildings, local producers, or electricity distributors.

**Expected impacts**

* 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 with each-other.
* End-users with active participation in the future smart grid environment.
* Allowing effective interaction with external world, including

other buildings, local producers, or electricity distributors.

**Suggested roles of stakeholders in implementation**

* *Public sector, building clients:*Public bodies must work to raise the awareness of the citizens and companies to the benefits of using renewable energy in buildings and the technologies needed for brokerage.
* *E2BA*: Enabling Energy brokerage among end-users should be added on the section “2.1.6 Performance monitoring and management”, section “The smart-cities initiative” for 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 (Energy Service Companies) should take into account new business models related to energy brokerage.
* *Standardisation bodies:*Develop/ harmonise standards for BMS, local energy systems and grids.

# Conclusions

## Comparison against the Description of work (DoW)

The REEB roadmap was used as baseline and complemented with EeB PPP Multi-annual Roadmap to derive the updated roadmap consisting of vision and SRA. The implementation activity plan was developed based on the stakeholder’s feedback.

The following tasks were executed and reported in D2.4 including the revising of the roadmap based on the feedback from stakeholders:

* Selected experts were involved to elaborate synergies and multidisciplinary areas of research within the EeB PPP Multi-annual Roadmap and its Implementation Plan.
* The initial version of the roadmap (D2.3) was presented at the validation Workshops (organised by WP4) with the experts group for feedback on contents and priorities.
* The refined Research Roadmap defines objectives and timeframe for future research topics and activities: multi-disciplinary research, demonstrations, dissemination, best practice promotion, education and training, innovation policies, standardisation etc.

The following figure represents the process:

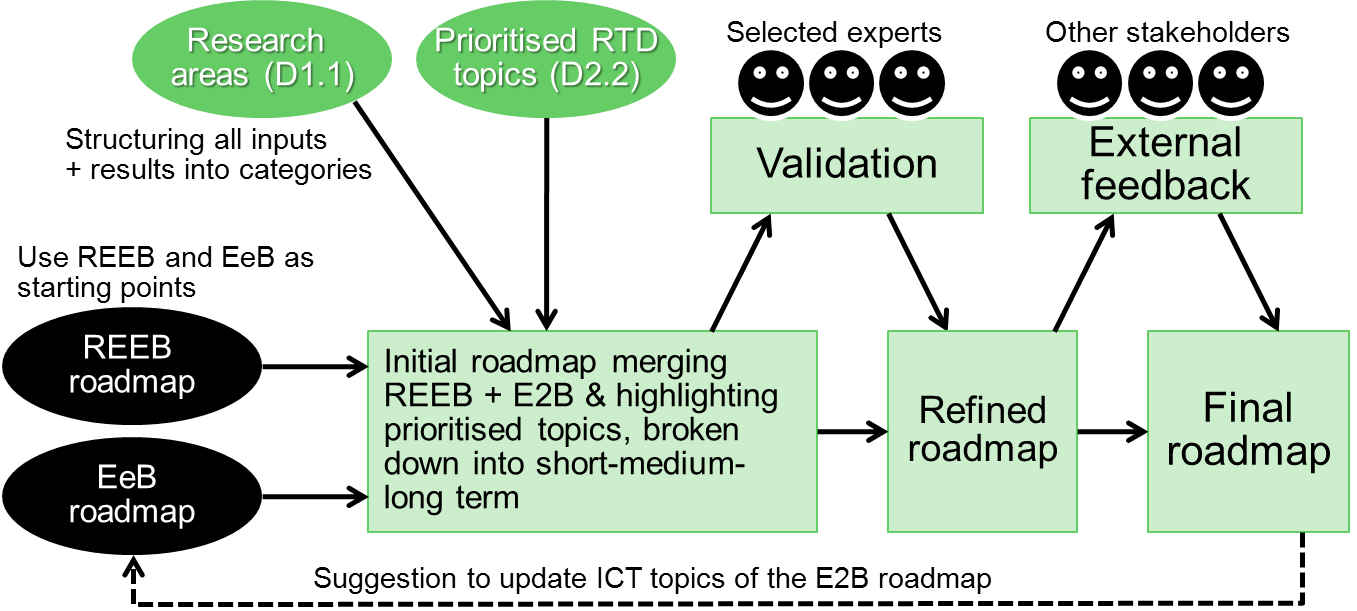


Figure : Methodology based on the DoW

## Roadmap Validation

The initial version of the roadmap was presented, for feedback on contents and priorities, at the validation workshops with the experts from different stakeholders groups. A web questionnaire was also developed and is open as used in deliverable D2.2 Prioritised gaps. The roadmap validation results will bedescribed in detailed under the task T4.3 “Forum activities management and interaction with stakeholders” in the forthcoming deliverable D4.6 Executive summary of results and recommendations”.

The events where feedback was collected were:

* CEBIT Trade Fair in Hannover
* Clean Energy and Sustainable Buildings Conference Poland, Warsaw
* GRIDplus Clusters and Functional Objectives - EEGI Roadmap, Brussels
* Innovative City Convention, Nice
* Smart City Event, Amsterdam

## Main findings

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. Strengthening the research investments in Information and Communication Technologies (ICTs) in relation to the building sector plays an important 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.

Previous work conducted in REEB and EeB provided a solid ground for the research roadmap presented in this document. New technologies were not identified; however the developments in interoperability and standardisation might lead to the consolidation of existing technologies. Anincreasing focuses and overall change to user-centric and district level solutions can be seen.

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 document aim to encourage a closer dialogue and a more active cooperation between researchers, end-users, practitioners, building owners, technology suppliers, and software engineers.

A significant group of various stakeholders was involved in the ICT4E2B Forum roadmap through workshops, community building activities and web questionnaires. They participated in the roadmap activities from the very first beginning, and thus profoundly discussed and validated the priorities addressed in the road map.

In addition to the road map, an implementation action plan was developed, identifying 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.

When technology solutions are discussed, it is clear that there is not one outstanding 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.

# Acronyms and terms

3D Three Dimensions

AIAG Ad-hoc industrial Advisory Group

BEMS Building Energy Management Systems

BIM Building Information Modelling

BMS Building Management Systems

CAD Computer Aided Design

Cloud technology Computing as a services, which includes different compilation of hardware, networks, storage, services, and interfaces

CO2 Carbon di Oxide

DoW Description of Work

DSO Distribution System Operator

DSS Decision Support System

E2BA Energy Efficient Buildings Association

EE Energy Efficiency

EeB Energy- Efficient Buildings

EPBD Energy Performance of Buildings Directive

ESCO Energy Services Company

ETPs European Technology Platform

EU European Union

FME Feature Manipulation Engine

FP Framework Programme

HMI Human-machine interfaces

HVAC Heating Ventilation and Air-conditioning

ICT Information and Communication Technologies

ICT4E2B ICT for Energy Efficient Buildings

IFC Industry Foundation Classes

IPD Integrated Project Delivery

IPR Intellectual Property Rights

IPv6 Internet Protocol version 6

IVEL Integrated Virtual Energy Laboratory

JTIs Joint Technology Platforms

KPI’s Key Performance Indicators

PPP Public-Private Partnerships

PV Photo Voltaic

R&D Research and Development

RFID Radio Frequency Identification

RTD Research and Technology Development

ROI Return on Investment

SRA Strategic Research Agenda

SOA System Oriented Architecture

WSN Wireless Sensor Networks

# References

[1] Hannus, Matti; Kazi, Abdul Samad; and Zarli, Alain, Eds.ICT Supported Energy Efficiency in Construction - Strategic Research Roadmap and Implementation Recommendations, 2010 REEB Project Consortium

[2] EeB - The Ad-hoc Industrial Advisory Group, *Energy-Efficient Buildings. Multi-AnnualRoadmapand Longer Term Strategy*, 2010(<http://www.ectp.org/groupes2/params/ectp/download_files/36D1191v1_EeB_Roadmap.pdf>)

[3] Classified research areas. ICT4E2B Forum, Deliverable 1.1, 2010

[4] Initial analysis of the state-of-the-art.ICT4E2B Forum, Deliverable 1.2, 2011

[5] Initial analysis of research projects.ICT4E2B Forum, Deliverable 1.3, 2011

[6] Application scenarios.ICT4E2B Forum, Deliverable 2.1, 2011

[7] Prioritised gaps.ICT4E2B Forum, Deliverable 2.2, 2011

[8] Draft Research Roadmap. ICT4E2B Forum, Deliverable 2.3, 2011

[9] Commission of the European Communities, European Economic Recovery Plan 2008

[10] [www.e2b-ei.eu](http://www.e2b-ei.eu)

[11]Stamatis Karnouskos, DejanIlic, and Per Goncalves Da Silva, “Using Flexible Energy Infrastructures for Demand Response in a Smart Grid City,” in The third IEEE PES Innovative Smart Grid Technologies (ISGT) Europe, Berlin, Germany, 2012 14–17 October.

[12] e-Diana EU research project - <http://www.artemis-ediana.eu/index.php>

[13] Encourage Eu research project - <http://www.encourage-project.eu/en/about_encourage/>