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European strategic research **R**oadmap to ICT enabled
Energy-**E**fficiency in **B**uildings and constructions

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D4.2 Strategic Research Roadmap for ICT supported Energy Efficiency in Construction

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Summary

This document builds on a previous REEB report "D4.1 Vision for ICT supported Energy Efficiency in Construction" by suggesting RTD priorities at various time spans:

- Short term: Buildings meet the energy efficiency requirements of regulations and users.
- Medium term: The energy performance of buildings is optimised considering the whole life cycle.
- Long term: New business models are driven by energy efficient "prosumer" buildings at district level.

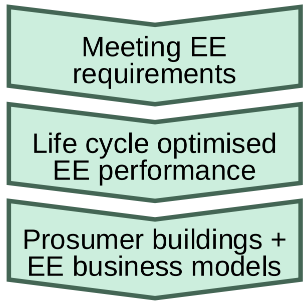

Figure 1. Envisioned evolution of energy efficient buildings

ICT contributions to the energy efficiency of buildings are mainly via a multitude of design tools, automation & control systems, decision support to various stakeholders throughout the whole life of buildings, etc.

Full exploitation of the opportunities offered by ICT for energy efficiency requires changes of the processes and contractual practices of the construction sector. The core is a transformation of focus from the initial construction cost to whole life performance i.e. value to owners, especially with regard to energy performance *(Figure 2)*. Although "Performance driven business models" are seen as the main drivers for energy efficient buildings, they are regarded to be outside of the scope of REEB, which is concerned about the ICT enablers.

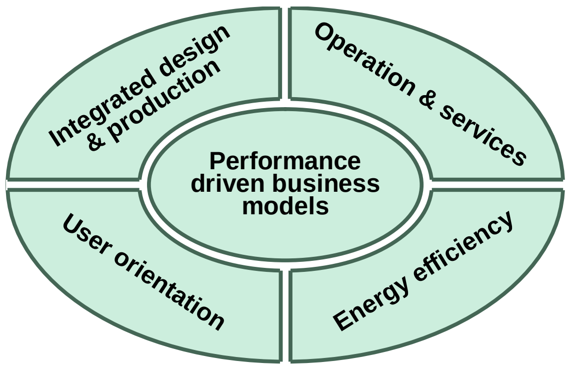

Figure 2. Industrial priorities

In order to align with the industry's priorities the REEB project presents its results organised into corresponding categories of research topics *(Figure 3 and Table 1)*:

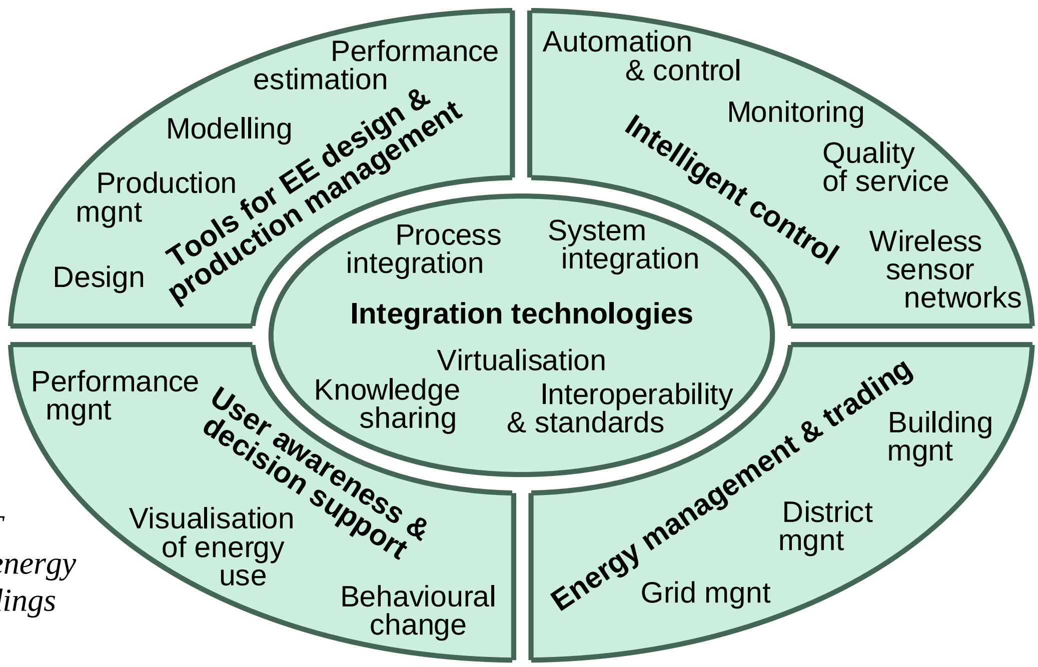

Figure 3. ICT enablers for energy efficient buildings

Table 1. Summary of proposed RTD topics

<table>
<tr><th colspan="2">Categories and subcategories</th><th colspan="3">RTD topics</th></tr>
<tr><td rowspan="4">Tools for EE design & production management</td><td>• Design</td><td colspan="3">CAD;Various other analysis and design applications; Configuration management; Visualisation of design solutions.</td></tr>
<tr><td>• Production management</td><td colspan="3">Contract and supply network management; Procurement; Logistics; On-site and off-site production management:</td></tr>
<tr><td>• Modelling</td><td colspan="3">Building and district energy models; Ontologies; Semantic mapping.</td></tr>
<tr><td>• Performance estimation</td><td colspan="3">Simulation; Whole-life costing; Life cycle assessment.</td></tr>
<tr><td rowspan="4">Intelligent and integrated control</td><td>• Automation & control</td><td colspan="3">System concepts; Intelligent HVAC; Smart lighting; ICT support for microgeneration and storage systems; Predictive control.</td></tr>
<tr><td>• Monitoring</td><td colspan="3">Instrumentation; Smart metering.</td></tr>
<tr><td>• Quality of service</td><td colspan="3">Improved diagnostics; Secure communications.</td></tr>
<tr><td>• Wireless sensor networks</td><td colspan="3">Hardware; Operating systems; Network design.</td></tr>
<tr><td rowspan="2">User awareness & decision support</td><td>• Performance management</td><td colspan="3">Understanding ICT impacts; Performance specification; Performance metrics; Performance analysis and evaluation; Conformance validation; Commissioning; Audits; labelling.</td></tr>
<tr><td>• Behavioural change</td><td colspan="3">Visualisation of energy use; Real time pricing.</td></tr>
<tr><td rowspan="3">Energy management & trading: buildings, districts, grids</td><td>• Real-time response and predictive management</td><td>Embedded sensing, automation and control; Real-Time Self Assessment; Network planning; Condition and Performance-based maintenance:</td><td rowspan="2">Performance analysis and evaluation; Secure, ubiquitous communi-cation</td><td rowspan="3">Decision support algorithms</td></tr>
<tr><td>• Enhanced design and integration</td><td>Network planning; Plug and play scalable integration of micro-generation and storage</td></tr>
<tr><td>• Distributed generation and demand response</td><td>Demand response capabilities; Load balancing techniques;</td><td></td></tr>
<tr><td rowspan="5">Integration technologies</td><td>• Process integration</td><td colspan="3">Collaboration support; Groupware tools; Electronic conferencing; Distributed systems; Business work flows.</td></tr>
<tr><td>• System integration</td><td colspan="3">Plug & play; Connections, Service oriented architectures; Integration and service platforms; Cabling; Gateways; Middleware; Development methods and tools.</td></tr>
<tr><td>• Interoperability & standards</td><td colspan="3">BIM standardisation; Simulation and interoperability; Protocols for real time operation; Energy trading protocols.</td></tr>
<tr><td>• Knowledge sharing</td><td colspan="3">Access to knowledge; Knowledge management; Knowledge repositories; Knowledge mining and semantic search; Long-term data archival and recovery.</td></tr>
<tr><td>• Virtualisation of built environment</td><td colspan="3">Office optimisation; Virtualisation; Electronic conferencing; Virtual workplaces; Dematerialisation of physical processes.</td></tr>
</table>

Contents

Abbreviations

3D .... 3 Dimensional
AEC ..... Architecture, Engineering and Construction (sector)
AMI ..... Advanced Metering Infrastructure
API .... Application Programming Interface
BAS ..... Building Automation System
BEMS .. Building Energy Management System
BIM...... Building Information Model
BMS ..... Building Management System
CABA .. Continental Automated Buildings Association
CAD ..... Computer Aided Design (tool/system)
CO .... Carbon Monoxide
CO2 ...... Carbon Dioxide
DEM .... District Energy Management
DGNB .. Deutsche Gesellschaft für Nachhaltiges Bauen
DSO ..... District System Operator
ECTP ... European Construction Technology Platform
EE .... Energy Efficiency / Energy Efficient
EEB ...... Energy Efficient Building
eeBIM .. Energy Extended BIM
ESCO ... Energy Service COmpany
FM .... Facility Management / Manager
GHG ..... Greenhouse Gas
GUI ...... Graphical User Interface
HVAC.. Heating, Ventilation and Air Conditioning
HW ...... Hardware
I/O .... Input / Output
iBMS ... Intelligent Building Management System
ICT ...... Information and Communication Technology
ICT4EEB .. ICT for Energy Efficient Buildings
IDM .... Information Delivery Manual
IFC ...... Industry Foundation Classes
IIC .... Intelligent and Integrated Control
LEED... Leadership in Energy and Environmental Design
MVD ... Model View Definition
NFC ..... Near Field Communication
OS........ Operating System
PC........ Personal Computer
PLC ..... Power Line Communication
PV........ PhotoVoltaics
QoS...... Quality of Service
RTD..... Research and Technology Development
SaaS..... Software-as-a-Service
SOA..... Service Oriented Architecture
SW....... Software
VOC .... Volatile Organic Compounds
WSN.... Wireless Sensor Network

1 Introduction

1.1 Scope and context

This report is the second one in a series of four REEB WP4 deliverables: Vision, Roadmap, Implementation recommendations and a Book summarising all results. The scope is ICT supported energy efficiency of buildings (ICT4EEB). This topic is in the intersection of 3 disciplines: building/construction, ICT and energy. Some examples of relevant items for an integrative approach are listed in the below figure.

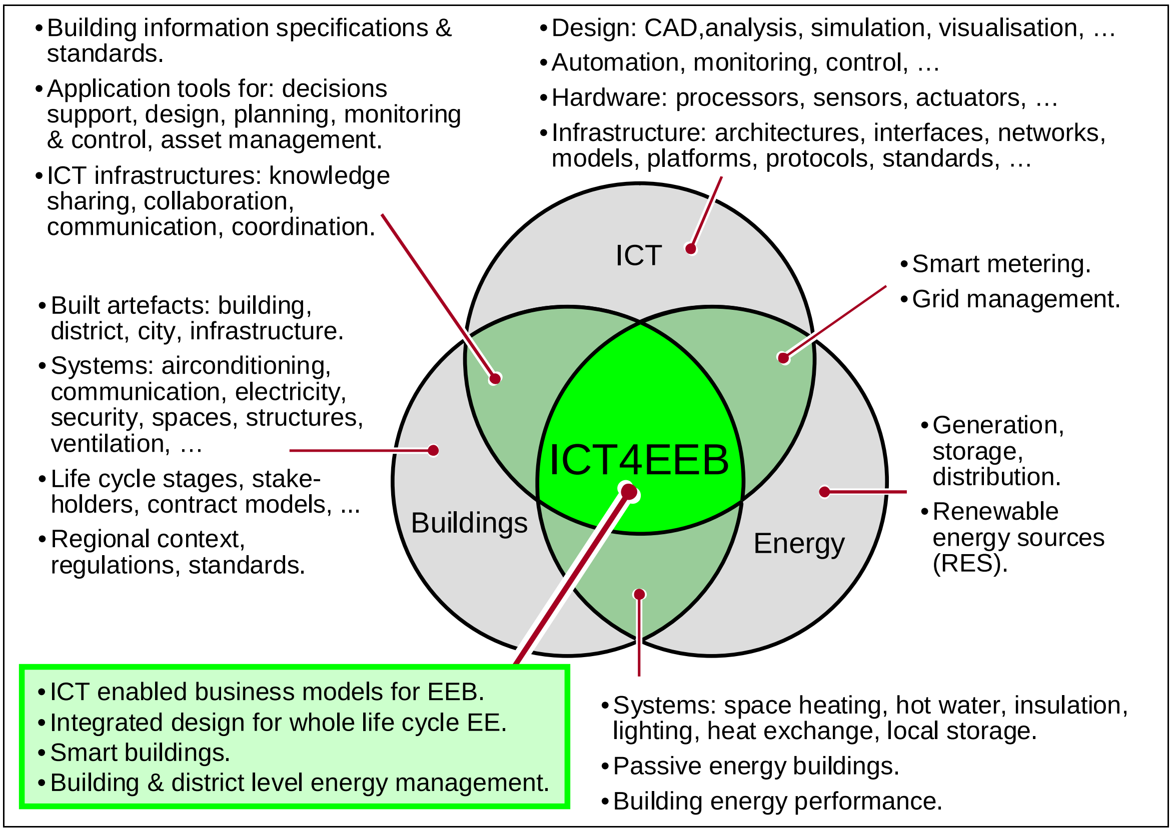

Figure 4. Scope of the ICT4EEB vision: integration of technologies for buildings, ICT and energy

This public deliverable is prepared by REEB Task 4.2: Develop and Validate Strategic Research Roadmap. It is based on the previous WP4 deliverable D4.1 Vision for ICT supported Energy Efficiency in Construction. The baseline of the work is provided by the EC policies and the visions and strategies of a number of related initiatives. The purpose, together with the other WP4 documents listed below, is to identify RTD priorities for ICT supported energy efficient buildings.

The key target groups the "ICT4EEB community" including e.g. European Technology platforms and RTD projects in the 3 core areas of focus, and the European Commission.

In the short term the immediate target group of this report is the REEB consortium for continued work and the REEB Special Interest Group, who advices REEB in the preparation of RTD strategy for the domain

The deliverables of WP4, including this report, are:

- D4.1 Vision for ICT supported Energy Efficiency in Construction
- D4.2 Strategic Research Roadmap for ICT supported Energy Efficiency in Construction.

- D4.3 Suggestions for Implementation Actions for ICT supported Energy Efficiency in Construction.
- D4.4 Book: Strategic Research Roadmap and Implementation Recommendations for ICT Supported Energy Efficiency in Construction.

1.2 Energy usage in buildings

Most energy usage of buildings throughout their life cycle is during the operational stage (~80%). The decisions made in the conception and design stages of new buildings, as well as in renovation stages of existing buildings, influence about 80% of the total life cycle energy consumption. The impact of user behaviour and real-time control is in the range of 20%.

Currently the energy performance of buildings is mainly driven by regulations. The prevailing market practice is driven by initial investment cost with little attention to life cycle costs. The awareness of energy efficiency is raising business incentives towards sustainable solutions beyond the required minimum level.

Most of the energy consumed by a building throughout its life cycle is consumed during its operational stage. The decisions that influence energy consumption are mainly made in the design stage and also in (repeated) renovations. Altogether, many stakeholders, parallel processes and life cycle stages are involved.

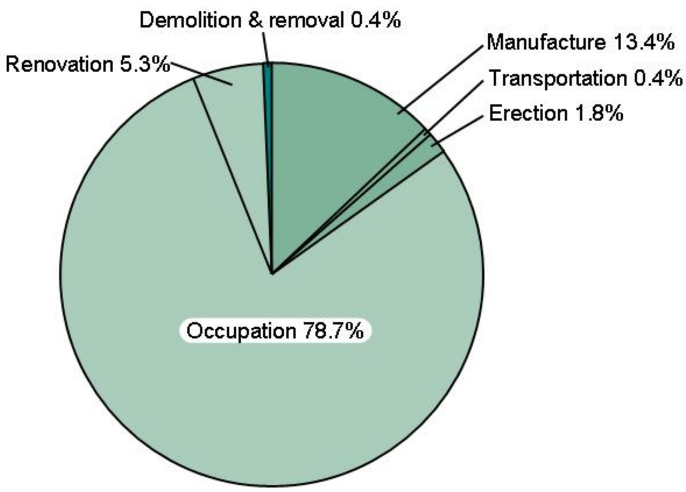

Figure 5. Energy use during life cycle of buildings [7]

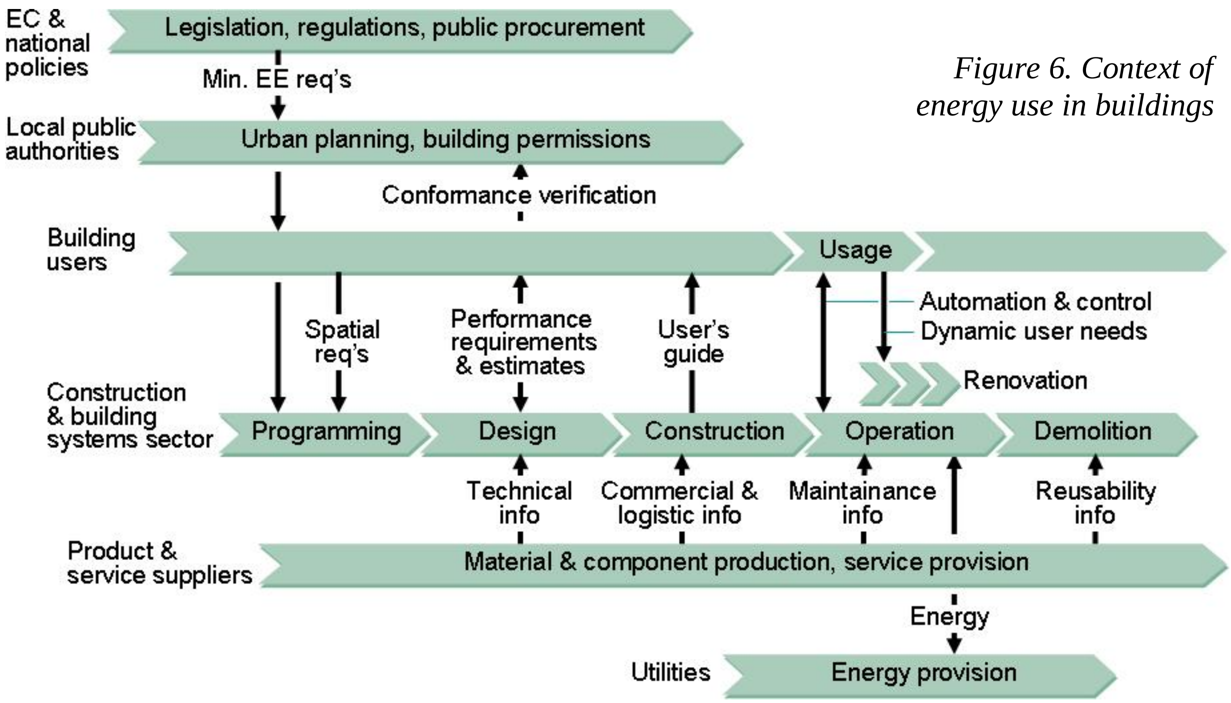

Figure 6. Context of energy use in buildings

1.3 ICT impacts on the energy efficiency of buildings

The relevance of ICT on the energy efficiency of buildings is mainly as follows:

- Short term: Assuring compliance to regulated minimum energy performance levels in design and renovation stages.
- Medium term: Decision support for life cycle cost/performance optimisation. Real time operation, control and user empowerment.
- Long term: Holistic optimisation of built environments considering: energy generation and usage of individual buildings, energy balancing between buildings within a district, responding to grid load and feeding excess energy into the grid. New business models driven by whole life time performance.

1.4 Structuring RTD priorities

A common taxonomy in the REEB project has been defined in order to ensure broad coverage of the scope of the ICT4EEB domain, to harmonise work within the project and to present the project results in a consistent way. All reports of REEB apply a similar structure with some variations depending on the specific contents. In this roadmap document the RTD topics are organised in the following categories:

1. Tools for EE design and production management

- Design: CAD, configuration management, visualisation of design solutions.
- Production management: contract & supply network management, procurement, logistics, on-site and off-site production management.
- Modelling: building & district modelling, ontologies, semantic mapping.
- Performance estimation: simulation, whole-life costing, life cycle assessment.

2. Intelligent control

- Automation & control: system concepts, intelligent HVAC, smart lighting, ICT for micro-generation & storage systems, predictive control.
- Monitoring: instrumentation: smart metering.
- Quality of service: improved diagnostics, secure communications.
- Wireless sensor networks: hardware, operating systems, network design.

3. User awareness and decision support

- Performance management: Understanding ICT impacts, performance specification, performance metrics, performance analysis and evaluation, conformance validation, commissioning, audits, labelling.
- Visualisation of energy use .
- Behavioural change by real-time pricing.

4. Energy management and trading

- Building and district energy management: building management systems, metering infrastructure, on-demand energy management and optimisation, load and distributed energy resources forecast algorithms, smart appliances.
- Smart grids: demand response capabilities, real-time self-assessment, load balancing techniques, energy network design and integration, secure, ubiquitous and low-latency communications.

5. Integration technologies

- Process integration: collaboration support, groupware tools, electronic conferencing, distributed systems, business work flows.
- System integration: plug & play, connections, service oriented architectures, integration and service platforms, cabling, gateways, middleware, development methods and tools.
- Interoperability & standards: BIM standardisation, simulation and interoperability, protocols for real time operation, energy trading protocols.
- Knowledge sharing: access to knowledge, knowledge management, knowledge repositories, knowledge mining and semantic search, long-term data archival and recovery.
- Virtualisation of the built environment.

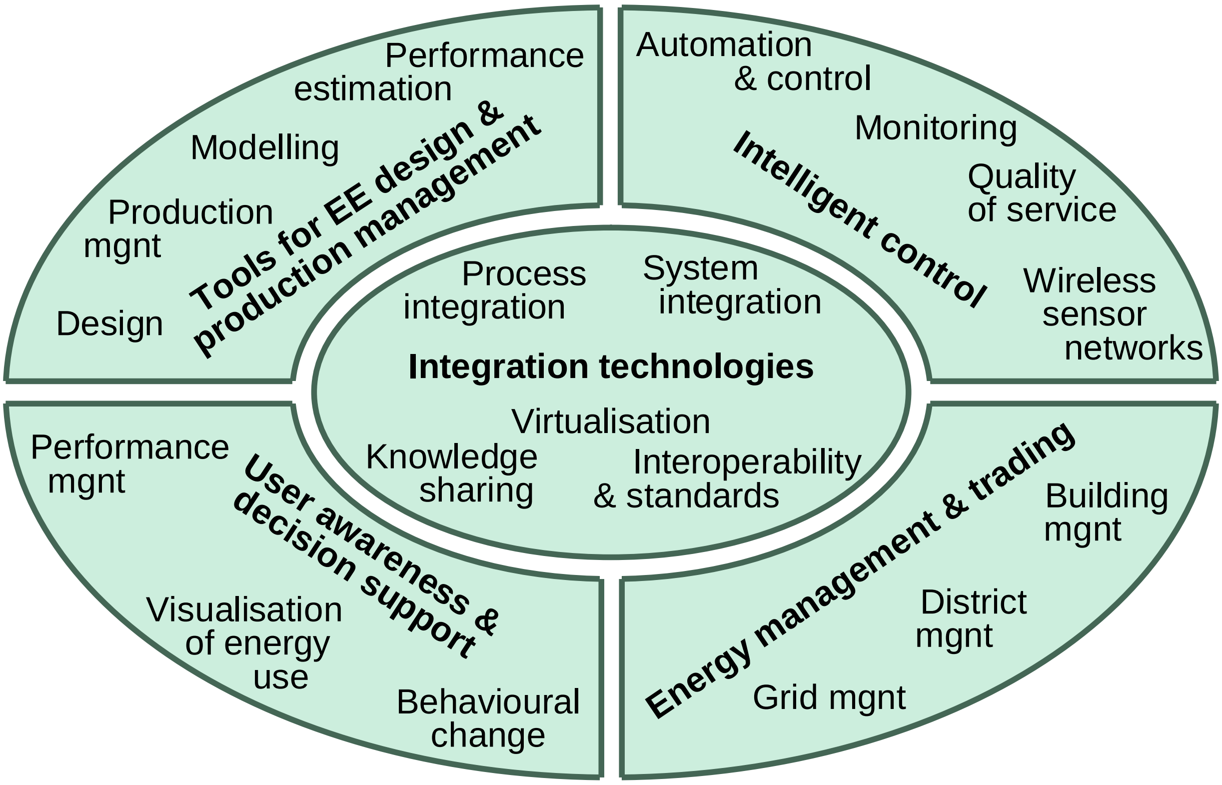

Figure 7. RTD priorities in the "ICT for energy efficient buildings" domain

Full exploitation of the opportunities offered by ICT for energy efficiency requires changes of the processes and contractual practices of the construction sector. The core is a transformation of focus from the initial construction cost to whole life performance i.e. value to owners, especially with regard to energy performance *(Figure 8)*. Although "Performance driven business models" are seen as the main drivers for energy efficient buildings, RTD on business models is regarded to be outside of the scope of REEB, which is concerned about the ICT enablers. The previous deliverable D4.1 Vision indicates some opportunities for new business models.

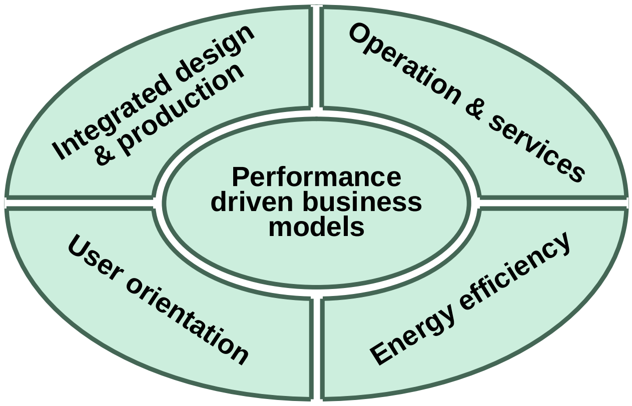

Figure 8 . Industrial sector priorities - the main drivers for ICT use

2 Strategic research topics

2.1 Tools for integrated design and production

Key research topics

This section presents five key research topics:

- Integrated engineering is a key to the definition of energy efficient buildings: integration of various tools to support a holistic process bringing together the views of different stakeholders to address the whole life of buildings.

  User interfaces: filter methods for creating model views, navigation in time-dependent multidimensional information spaces, visualisation.

  Improved theory and models of the energy behaviour of buildings, and the potential impacts of various ICT-based approaches on it. Validation and tuning of methods via comparison with monitored data.

  Integration technologies: Other generic technologies serving the integration of many different types of application are addressed in section 2.5. They include e.g.: ICT support for collaborative design and planning in a range of engineering tasks over the building life cycle; interoperability and standards, and Knowledge sharing technologies supporting accumulation and re-use of design experiences and proven solutions.

- "Design for energy efficiency" tools (D4EE) covering a broad range of CAD and other applications for design and planning of buildings - both new and existing to be renovated - and the urban infrastructure; configuration management for re-using and adapting proven solutions; visualisation of design alternatives and solutions. Reducing need for many special purpose tools via embedded EE functionality in already used design tools. Easy to use, simple EE tools for early stages of design.

- Production management covering: contracts & supply network management; procurement; logistics; on-site and off-site production management.

- Modelling: Building modelling (BIM), district modelling, model granularities, ontologies for eeBIM, semantic mapping; Standardized Semantic Data Models

- Performance estimation covering various methods that are used at design stage to estimate the performance of the building for decision making and contracts e.g. simulation, whole-life costing and life cycle impact assessment. Research topics include: Definition of performance indicators and methods to assess them using available information from various ICT systems; Validation / certification of SW tools; Virtual testing; Integration of BIM-CAD and simulation; Simplified EE assessment and optimisation; Integrated environment for EE assessment; EE knowledge base. Tools to estimate EE performance in a quantified and verifiable way.

Vision

Integration of BIM-CAD, dynamic energy simulation and visualisation: The planners (architects and engineers) are provided with appropriate means, such as simple energy estimation tools, so that the future building performance becomes obvious to them from the very beginning of design. The building service engineers are involved in an early stage, using energy simulation tools which are interoperable with the integrated BIM-CAD (Building Information Modelling) used by architects.

Information from energy validations based on local and/or European standards are visualized for decision making by stakeholders who are not necessarily energy experts. As the design evolves, more realistic energy analyses, using dynamic simulation methods, are made based on the increased granularity of the BIM. As a result, the building service equipment will be optimised, avoiding over- or under-dimensioning.

Virtual testing: The impacts on energy and emissions of new and improved building components (products), processes (e.g. building operation) and services can be tested in "Virtual Energy Lab" which is based on a building energy simulator.

Design for mass-customisation: Re-usable design solutions as parametric / configurable templates are available for adaptation into custom situations e.g. components, rooms/spaces, building services subsystems etc. ICT in this domain enables industrialised delivery of EE solutions for new and especially renovated buildings.

Integrated (distributed) engineering environment supports concurrent engineering between all stakeholders involved in the design and planning, and beyond - the whole subsequent life time of a building. It includes a suite of interoperable tools based on a common ontology and transparent services for data and model management.

Drivers

- Increasing regulatory requirements and client/user expectations regarding EE due to increasing energy costs.
- Emerging open construction market at EU level, calling for more industrialised, systemic and "branded" solutions.

Barriers

- Current contractual practice focuses on initial investment instead of whole life cost. Therefore the incentives are lacking for many stakeholders to take necessary actions for EE.
- Specialised ICT tools, extra efforts and special competences are needed for EE design, analysis & planning.
- Lack of experts and labour for extensive EE renovation of the European building stock.

Impacts

- Opportunities to software developers to provide new EE design/planning tools, interfaces to other tools, and to enhance existing tools with embedded EE features.

Scenario

The complexity of the energy system demands the integration of the several design stages. At each stage the building model shows a different granularity. Formalized models for all stages will be available, as well as model mapping. Intelligent tools and library templates will be available in each design stage, as described below, for instance. The design stages can be seen as the lifecycle of design:

Feasibility Design: Building is modelled in a few zones, which show the principle energy and emission information and behaviour. Predefined templates of zones are offered in intelligent libraries as semi-instantiated zone objects. In this phase basic energy scenarios are investigated and the classes of the energy subsystem (energy providing, heating, cooling, isolation, etc. systems) are determined. Alternatives are managed and the final decisions are transferred (mapped) to the next design step.

Preliminary design: Building is modelled in climatic zones where a zone reflects the group of rooms with similar kind of energy behaviour. The zone objects already show a granularity of external, internal and semi-exposed walls, ceilings, roofs, floors and sub-surfaces, windows areas, areas of permanent/semi- permanent openings. Again predefined templates are available in intelligent libraries. In this phase the components of the basic subsystems are determined, which means, the class of windows, wall structure, boiler, ventilation, etc. and their location are defined.

Final Design: Each room is a climatic zone, and rooms may be subdivided into several climatic zones or several rooms are united into one climatic zone. This switching back and forth can be done smoothly. For each zone an iterative modification of energy related information is possible to run simulation alternatives. Also the whole building, parts of the building are modelled and simulation results presented on different time scales (time resolution) and granularity of the building (level of detail). In this phase the product types of each component and their exact location and interaction are determined. This is a sophisticated engineering task, because a system is to be assembled from components coming from different suppliers, where standardization is not always given.

Operation phase: During operation the actual building performance is compared with the designed performance. The system as given is tuned in the daily operation in order to improve delivery and efficiency.

Lifecycle Analysis: Life cycle considerations are possible for any of the four above modelling granularities. In this phase case studies are run to improve the operation of the system in the future concerning control and workflow and also to detect weakness or study new products, processes and services for improvement of the system which may accumulate in a renovation of the energy system or the whole building.

Related roadmaps/SRAs

The SRA of the ECTP [41] was prepared before the before report. Therefore it mentions ICT-related opportunities only at a general level.

The SRA of ECTP Focus Area "Processes and ICT" [48] presents ICT- and design related topics broadly, without emphasis on energy efficiency.

The Multi-Annual Roadmap for the Energy-efficient Buildings PPP [35] refers to related policies, European Council decisions and EU directives and calls for several research topics addressed in this section.

Table 2. Roadmap for EE design and planning

Drivers	Increasing EE requirements.	Life cycle optimised buildings.	EE driven business.
Barriers	Lack of interoperability. Need of many special tools and extra efforts for EE considerations.	Lack of client awareness, incentives and financial instruments. National / regional regulations.	Prevailing business models focusing on delivery costs instead of value to client.
Impacts	Compliance at lowest cost.	EE services.	Branding.

<table>
<tr><th>State of the Art</th><th colspan="2">Short term</th><th>Medium term</th><th>Long term</th><th>Vision</th></tr>
<tr><td>Design: Discipline-oriented analysis & dimensioning tools. General purpose CAD with discipline oriented add-ons.</td><td rowspan="2">Enhancement of existing design tools with EE features.</td><td>Tools for early stage design. Interoperable interfaces.</td><td>GUIs for data filtering, navigation and visualisation. Catalogues with EE aspects. Advanced analysis tools.</td><td>Specialised tools for “creative design” and “configuration mgnt”. Template solutions for customised configuration.</td><td rowspan="5">Integrated model-based tools with embedded consideration of EE aspects in a transparent way.
Catalogues of all re-usable knowledge.
Standardised data model covering all EE aspects.
Interoperability between all SW tools for design, production mgnt and operation.
Contracts based on models and life cycle EE performance.</td></tr>
<tr><td>Production mgnt: Tools for contract & supply chain mgnt, procurement, logistics, on/off site production mgnt.</td><td>Material and product tracking systems.</td><td>Adding EE aspects to catalogues of materials and products. Tools to optimise production EE as part of life cycle.</td><td>Tools for rapid and flexible project team formation and mgnt.</td></tr>
<tr><td>Integrated engineering: Web-based document mgnt systems.</td><td colspan="2">Guidelines for integrated design.</td><td>Collaboration platform for concurrent building engineering.</td><td>Integrated design environment. Model driven workflows.</td></tr>
<tr><td>Modelling: Mostly document oriented tools. Model based tools are emerging (e.g. BIM-CAD).</td><td colspan="2">Take up of available model based tools.</td><td>Enhancement of data models (ontologies) to cover EE aspects.</td><td>Model servers. Integration of design models (BIM) with operational near-real-time information.</td></tr>
<tr><td>Performance estimation: Numerous distinct tools for cost estimation, life cycle assessment and simulation.</td><td colspan="2">Validation / certification of SW tools. Definition of performance metrics.</td><td>Integration of EE assessment with design tools. Interoperability with real time diagnostics.</td><td>Tools to estimate EE in a quantified and verifiable way – sufficient for performance based contracts.</td></tr>
</table>

2.1.1 Design

State of the art

Design tools: There is a huge variety of applications for the design of buildings, technical equipments, urban plans. In this document we address only the generic aspects of these tools without going into application specific details. The methods and tools are mainly developed in parallel and independently. Many tools are made in-house by user companies or are provided by SME developers, often on national basis. General purpose CAD tools are provided by major software companies. Most tools address mainly detailed design, while only few support other design phases. Although advanced tools and methods are available for each discipline, they are mainly stand-alone, designed for experts, with limited flexibility and lacking interoperability concerning models and design cultures. Special purpose tools need to be used for energy related issues as they are not covered by mainstream tools.

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

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

Short term RTD priorities

EE enhancements: CAD tools should be enhanced concerning energy related data models and information.

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

Interoperable interfaces: Improved interoperability to support optimal energy efficient design of a building in continuously evolving cycles between architectural and energy engineering design: selection of the basic principles of energy mix and the basic energy systems, design of the energy distribution system and components and specifying the technical details. Model consistency checkers, e.g. as web services, are needed to validate interoperability.

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

Medium term RTD priorities

GUIs: Enhanced user interfaces for generation of the building geometry and navigation in complex information spaces, mapping and filtering of data for different design aspects and stages, and visualisation of design alternatives to different stakeholders.

Knowledge based design: Knowledge bases should be developed to cover energy related data e.g. materials, products, services, climate, users' activity profiles etc. Support re-use of systemic design solutions by “parametrics” and “configuration management”. These approaches apply mainly for non-creative design where a pre-developed solution “template” is customised into a specific situation. The templates can be defined as software objects encapsulating design rules and constraints, and interfaced via a set of open parameters. Publishing catalogues of such intelligent template objects offers various new business models.

Collaboration platforms should be developed to support concurrent engineering between various stakeholders involved in design and planning.

Advanced analysis tools: First, there are Multizone Building Energy Solvers for the analysis of climatic conditions in rooms and multizone energy flows in buildings. Second, there are Building Envelop System Solvers for the analysis of the transient behaviour of the building envelop, including the behaviour in those internal walls that separate different climatic zones or rooms and which are important for the durability analysis, like moisture transport or accumulation. These are complemented by a third kind of tools, which provide code compliance checking. These tools will ultimately automate the interpretation of codes for energy efficiency. The codes are very complex, up to 1000 pages varying from country to country, and often lack transparency.

Long term RTD priorities

Integrated design environment: Bundling of specialized tools (such as those counted under short and medium term) and seamless integration in the design environment. The system has to be based on a common ontology and complemented with orchestration descriptions for different use scenarios in order to provide to the end-users an integrated efficient working system. The environment shall provide transparent data and model management. Naturally some services may be transparently outsourced to third parties as web services e.g. model filters (for generating model views) and model consistency checkers.

Model driven workflows: As model/BIM-based design becomes commonplace, also the design process itself can be modelled enabling model-driven information and work flows.

2.1.2 Production management

State of the art

Similarly as for design, a large variety of software tools are used for process & production management in construction. Many tools are developed in-house or SME vendors. Often these are for national markets due to local regulations and contractual practices. Thus only a few tools are from major international software companies e.g. scheduling and resource planning. The main aspects addressed for production management are related to timing, costs and contracts. Energy efficiency, and sustainability in general, is an emerging concern.

It is considered that today about 10% of all CO_2 emissions globally come from the production of building materials. In particular steel, concrete/cement, bricks and glass require very high temperatures that can only be reached today by the burning of fossil fuels. Construction activities account for about 5% of energy used, including construction related transport [4]. Construction and demolition waste account for about 22% of all waste [5].

Short term RTD priorities

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

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

Medium term RTD priorities

Design optimisation for improving constructability and re-usability, and for reducing the weight and volume of manufactured products and modules.

Methods to optimise energy efficiency as a combination of product performance and services.

Decision support tools regarding onsite vs. offsite production.

Logistics optimisation for reducing transportation distances considering multiple supply sources and local procurement.

E-catalogues and e-business platforms to support re-use of building materials, components and waste.

Integrated building life cycle assessment (LCA) methods considering energy efficiency throughout supply networks.

Long term RTD priorities

Models, methods and tools for understanding and aligning the incentives of various stakeholders towards whole life performance of the building. New tools for preparation and enactment of performance based contracts.

2.1.3 Modelling

State of the art

Building Information Modelling (BIM) has become the key technology for representing data about products within the AEC and FM industries for design, energy simulations and performance estimation. It's use also in building automation & control is emerging. Ideally BIM consolidates available product data from different sources[1] to provide high quality and up-to-date information about buildings. Thus it has the potential to act as a single point of information that can be used by various applications avoiding time consuming, error-prone and costly re-entering of data. The current use of BIM is mainly for file based data exchange while data sharing using model servers in under early development. The existing data models still miss most concepts needed for EE analyses. Due to limited scope of existing models and lack of supporting tools, expertise on BIM and laborious efforts are often needed to achieve interoperability.

Standards for implementation: The international IFC-Standard (ISO-PAS 16739) developed by the non-profit buildingSMART initiative [9] is supported by all major CAD software vendors in the AEC market. However, also other data models, such as gbXML[2] [22] or proprietary formats from software vendors, are relevant. In order to deal with multiple data models the following extensions to the overall BIM concept have been established:

- Information Delivery Manual (IDM) specifies business needs independently from any particular data model. An IDM defines processes and exchange requirements between domains such as architecture, building services engineering (HVAC) or facility management. [49]

[1] At the moment it is focused on design domains such as architecture, HVAC or structural engineering but more and more becomes interesting for facility management and operational data.

[2] gbXML is currently not used in the European market.

- Model View Definitions (MVD) provide mappings to specific data models, such as the IFC 2x4 release, including further implementation agreements. [23]

Data validation: Whereas the benefits of BIM-based energy analysis have been demonstrated in several research projects[3], there are still problems related to data quality and maturity. Methods for data validation are needed. Using BIM data for energy calculations still requires a lot of manual work. This becomes critical in particular if several iterations are needed for energy optimization purposes.

Short term RTD priorities

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

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

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

Medium term RTD priorities

Structural extensions of BIM: The modeling needs to support various domain oriented views. The BIM model has to be extended (and of course the interfaces and modelling capabilities in the CAD, energy and other tools) to cope with back and forth switching between different design and testing phases that use different levels of granularity and different decomposition structures regarding e.g. building components, climatic zones and building services systems. Instead of defining new domain specific objects, it should be possible to use the same basic objects, and to assemble, disassemble and rearrange them for different systems.

Extendable data structures should be developed as the baseline for the integration of CAD and energy analysis tools and furthermore the extension of these integrated tools to a simulation platform. Model view definition and mapping methods have to be considerably further developed. Further development should cover, not only data transformation, but also model transformation, model mapping and model filtering (model views). Partially these functionalities can be separated, generalized and made available as web-services.

Long term RTD priorities

Integration of BIM with operational near-real-time information**:** Harmonisation BIM and real time data for building automation and control. This will enable comparison of designed and actual performance.

Distributed model and data management: For an integrated EE-design system, preferably a SOA based platform system, a fully developed product model (BIM) data management system (“model server”) has to be provided. These systems should no longer be centralized turn key systems but the data management functionality should be provided as web services. These web services should support advanced model view filtering, model comparisons, model

[3] www.inpro-project.eu, http://standards.eu-innova.org/Pages/StandInn/default.aspx

normalisation, model matching and model merging just to name only the basic functionalities. The management system should support advanced versions and alternatives management, a very important task not only for design but also for system identification in the operation phase. The web services should be embedded and controlled by an ontology to seamless exchange information between basic tools and supporting tools (like navigators, visualization, gap analysers, etc.).

Model driven EE construction business: Integrated theory and related methodologies for modelling and rapid engineering of dynamic project-based business processes and networks. Tools to decompose EE performance criteria into measurable requirements to all involved stakeholders and methods to assess compliance. Configuration tools for consortium formation, contract preparation, ICT integration and performance assessment.

2.1.4 Performance estimation

State of the art

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

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

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

Short term RTD priorities

Energy estimation in early design stage: There should be development of ICT tools energy calculations already in earlier planning phases for new buildings or renovation of buildings – providing information to the architect in a way that it is accessible to him while not being a real energy expert. For this purpose, both BIM-CAD and energy simulation applications have to be extended with appropriate data and interfaces.

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

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

Validation & certification of SW tools: A standardised methodology (at national level, and for European countries) to validate performance estimation tools would mean a more comprehensive approach to building assessment, and is therefore required in a short term. Using monitored data from real buildings to validate and improve performance estimation models and fine-tuning the theory.

Virtual testing environment: Important impact on energy and emission reduction is through improvement of building components (products), processes (e.g. building operation processes) and services, because they can be applied to any or many buildings (new and the existing stock). As the testing and evaluation of all products and services may reveal quite complex and expensive, there is a need to test them before their realization with objective variations of the building type, user scenarios and climatic scenarios: a building energy simulator for the architect is to be extended to the concept of *Virtual Energy Lab*, which may be done with small effort, namely to provide an input for new products, processes and services to the virtual world.

Simulation: In particular, new tools for building energy performance simulation and methods for interfacing simulation models for whole buildings and building envelope parts needs to be developed.

Medium term RTD priorities

Embedded energy anaysis: Integration of EE assessment within existing design tools in order to reduce the need for many special purpose tools and required expertise to use them.

Simplified EE assessment and optimisation: Light-weight tools should be developed with drastically reduced data input for simplified assessment of the building performance. They could be extended with global optimisation techniques (e.g. genetic algorithms and/or neuronal networks) to fasten / accelerate the computing of near-optimal global solutions.

Interoperability with real time diagnostics: Methods to compare estimated performance with actually monitored performance.

Integrated environment for EE assessment: New tools and collaborative platforms must be developed to obtain interoperability and integration among stakeholders for EE buildings design, construction and management. A further step is integrate local existing platforms and tools with their country-related specificities. Such platform should provide access to wide scientific and technical knowledge in a database.

EE knowledge base: A European-wide database [35] of possible (optimal) technical interventions and their effect in real buildings can also support the cost- and energy effective retrofitting of buildings. Such an ICT system will establish a link between theoretical modelling (from fundamental research and simulation) and experimentations on real buildings: proposed new interventions can be assessed via simulations and compared with real measured data.

Long term RTD priorities

Tools to estimate EE in a quantified and verifiable way: The ultimate step will be to offer to construction stakeholders and energy engineers tools allowing them to establish, control, assess and certify optimised energy consumption in any kind of buildings, with easy and fluent mechanisms to do so. This can be envisaged through performance estimation tools and platforms offering e.g.:

- more powerful visualization methods for simulation representations, comparisons of alternative options, what-if analysis etc.;
- seamless navigation in time-dependent multidimensional information spaces, in particular to visualize the interdependencies of granularities of models and systems in an easy-to-understand way in order to allow a target oriented design and to keep overview of the different simulations and estimations carried out in the scope of the design.

Such assessment, simulation and visualization tools are needed to support decision making, removing gaps between prediction and reality. These performance estimation tools / platforms will require the development of model based ICT applications integrating object-oriented design with customizable parameters. They will also have to achieve *user interoperability*: in order to support co-operative performance estimation of the designers, FMers and to integrate building owners as well as building users, commonly understandable interfaces, visualization and navigation must be provided, related to the individual knowledge and the information needs of the individual persons.

2.2 Intelligent & Integrated Control

Key research topics

Four main concepts are the basis of "Intelligent & Integrated Control" and should constitute key research topics:

- **Automation and control** consisting in methodologies, procedures and ICT systems that are able to manage (through actuators and embedded systems) all energy production and usage in a building, according to information received from inside the building (user interfaces, sensors, appliances, energy devices – production, storage, consumption) and outside (Internet, energy providers – ESCOs, district energy systems, weather, etc.) in order to ensure comfort, while optimizing the energy consumption of the building.
- **Monitoring** relying on the instrumentation of the building with smart meters, other sensors, actuators, micro-chips, micro- and nano-embedded systems that allow collecting, filtering and producing information locally. This huge amount of distributed information is consolidated by a global monitoring system, in liaison with the Building Management System.
- **Quality of service** covering issues such as improved diagnosis (allowing the monitoring and control system to auto-detect failures in the connected devices) and secure communications (ensuring full integrity of all data exchanges between applications).
- **Wireless sensors networks** enabling all energy (consumption, production and storage) systems and conditions measurement devices to communicate. Wireless networks are particularly necessary for existing buildings where redeployment of cables is impossible.

Vision

The future buildings, along with their components, equipments, and their environment will communicate and be able to provide information on their status ubiquitously. This real-time available information will be interoperable via common protocols for holistic automation & control. The whole building will be supervised by intelligent systems, able to combine information from all connected devices, from the Internet or from energy service providers in order to efficiently control HVAC (heating & cooling), lighting, and hot water systems along with energy production, storage and consumption devices inside the building, taking into account the users' needs and wishes.

Drivers

a) <u>Market segment of residential customers</u>

⇒ Dynamic electricity prices

Through the growing implementation of Smart Meters and the rising of Smart Grid technologies, dynamic electricity prices, changing for example every 15 minutes, will soon become reality. The huge saving potentials can be easily understood.

Therefore, each house will install its control system that communicates

- On the one hand with the Smart Meter, to get the current electricity price and the forecasted prices for the hours to come
- And on the other hand with the fridge and the freezer, the washing machine and the dish washer, the electrical heating, …

This is of course not really a pure IIC scenario but this kind of system will be an embryo

- Of a Building Management System (BMS) requiring control algorithms

- Of a communication infrastructure between a central instance of intelligence and devices that are distributed inside the building

And will make people understand the potential of ICT4EEB.

⇒ Increase of locally generated electricity, corresponding storage devices and e-mobility requiring local charging station

Closely linked to dynamic electricity prices, the growing importance of locally generated electricity (e.g. PV systems), and eventually of corresponding storage devices, and e-mobility requiring local charging station will increase the need for a BMS controlling and optimizing the electricity flow.

⇒ New regulations and standards for energy efficiency of buildings

New regulations and standards, at European and national levels, for energy efficiency of buildings are as well a natural driver for ICT4EEB. As an example, we can quote the Building Energy Performance Directive, and the recently launched Energy Efficiency in Buildings and Eco-Innovation initiatives as well as the Lead Market Initiative on Sustainable Construction.

b) Market segment of professional customers

For the professional segment, where BMS are already in place, the situation is somehow simpler. In this segment, we will have a more continuous evolution towards more and more sophisticated BMS driven by

- Increasing energy prices
- Increasing technological possibilities allowing optimized and integrated BMS
- Potentially stricter regulation concerning energy consumption and GHG emissions
- Rising of the Smart Grid and dynamic electricity prices, local production of electricity and corresponding storage devices.

Barriers

a) Missing quantitative proof of added value / of ROI

> ***For our professional customers, the possibility of predictive maintenance is a main reason to buy our products[4]***
> CEO of an ICT4EEB company selling and installing IIC systems
>
> ***Consumers, small businesses and landlords do not see the need for such a service [21]***

It is very difficult to know *a priori* by which degree IIC will diminish the energy bill. This is currently one of the main barriers for IIC.

It is thus one of the most important tasks for the ICT4EEB R&D community

- To develop commonly shared and accepted simulation tools enabling to prove in an undeniable manner the added value / the ROI of IIC
- To perform field tests, thanks to pilot houses for example.

b) Insufficient Interoperability

> ***Ideally, we could apply the principles of interoperability ('plug and play') to buildings, but the reality is rather 'plug and pray'.***
>
> Stephen SELKOWITZ, Program Head of the Building Technologies Department at the LBNL

[4] Meaning that purely financial ROI based on energy savings would not be sufficient

Insufficient interoperability prevents

- Sub-systems (e.g. HVAC, lighting , security, etc.) to collaborate
- Systems to be flexible enough to cover the whole lifespan of a building.

Commonly elaborated and shared standards, for example for data transmission protocols between concerned devices, will improve the situation. These standards must also take into account maintenance handling and QoS aspects.

c) Social barriers

Use of IIC will only be accepted if the user keeps the impression to remain master of what happens. Each system must thus allow manual control and this one must always have priority.

User acceptance also requires that the technology has to be hidden behind well designed user interfaces that can implement multi-modal interactions with the system.

d) Regulation barriers

Absence of European standards is a further barrier for IIC use.

A European label for EEB for example would certainly help to push ICT4EEB. Such a label would be a complement to the US label LEED [45], the UK label BREEAM [8], and the German national label of the DGNB [13]. Such a label must include formal guarantees that the performance of the system will remained unchanged for many years: reliability of components, QoS, quality labels, maintenance contracts with clearly defined liabilities, are some of the issues that have to be covered.

Impacts

a) An increasing demand for integrated Building Management solutions

The need for optimized Building Energy Management solutions

- Having a holistic approach combining HVAC, lighting, storage control, …
- Integrating all coming technological progresses in WSN

will increase pressure on BMS suppliers to offer integrated solutions.

b) New business opportunities thanks to interoperability standards

Interoperability standards will create an opportunity for new entrants that might develop interoperable modules of BMS (only the control part, only the predictive maintenance part…). Existing BMS actors might therefore evolve towards the role of a system integrator.

c) A struggle for market dominance in the Energy Box market

Given the importance of the Energy Boxes for the residential ICT4EEB market and given the fact that these boxes might be commercialized via Utility companies, smart partnering with the right Utility could be crucial for ICT companies.

d) A "MS Home" (EnergyPlus for everybody)

There will be a demand for software enabling a residential customer to simulate its house and estimate the impacts of a given ICT4EEB product on the market[5].

In a second step, each ICT4EEB product might even come with a kind of driver / add-on to be integrated in such a "MS Home" enabling the house owner to simulate the benefits of this given ICT4EEB product for his specific building, before buying the product.

[5] On a recent fair, a first prototype of this functionality has been presented. The application interfaces Google SketchUp (for modelling the house), Google Earth (to get weather data) and EnergyPlus.

Scenarios

a) Smart Box

It has been a windy night and wind farms were at maximum power. The electricity price level, communicated via the smart meter to the Energy box, was at 10% of the average daytime level. The Energy box decided to stock energy as cold in the freezer. When prices rose again, at about 5am, temperature in the freezer has reached -40°C. The energy box stopped the freezer. During the whole following day, and without any consumption of electricity at relatively high daytime level prices, the temperature of the freezer stayed below the value of -18°C.

b) Smart Office[6]

Tom stops by his office in a commercial building one Saturday evening. The proximity sensor reads Tom's smart card as he nears the front door. A security system verifies that Tom is indeed welcome, and unlocks the office door. The security system monitors Tom's entrance, making sure only one person enters, and automatically secures the door behind him. The building's air conditioning system is notified that Tom is on his way and begins to adjust his workspace to personalized settings. After several hours work, the building senses Tom's departure and returns to unoccupied settings. Intelligent sensors resume their watch as the security system is automatically rearmed.

c) Smart shutter[7]

Mr. Smith has bought a motorised rolling shutter and fixed it over a window on the outside south wall of his house. The shutter is immediately automatically identified and authenticated on the network.

The central controlling "assistant or manager" is now aware of the existence of this new smart shutter and updates its control algorithms integrating this new actuator.

- In summer, when air conditioning might be necessary
  - The shutter is rolled down when local weather forecast indicates "sun shines". However, when occupancy sensors indicate the presence of a habitant, the corresponding energy saving from air conditioning is compared to the additional lighting consumption.
  - As soon as the local weather forecast indicates "rain or clouds", the shutter is rolled up.
- In winter, when heating might be necessary
  - The shutter is kept rolled up when local weather forecast indicates "sun shines"
  - The shutter is rolled down as soon as lighting becomes necessary in order to increase isolation of the windows

Until now, no human parameterisation has been necessary. If however, the adapted shutter strategy is not well accepted, the touch screen interface of the shutter allows modifying its behaviour, according to the wishes of the current habitants.

Related Roadmaps/SRAs

- Strategic Research Agenda. ECTP Focus Area 7: Processes and ICT. 2008. [48]
- Energy-efficient Buildings (EeB) PPP: Research Priorities for the Definition of a Multi-Annual Roadmap and Longer Term Strategy [35]

[6] See reference [37]

[7] Adapted from reference [51]

Table 3. Roadmap for intelligent and integrated control

Drivers	Dynamic electricity prices, local production of electricity and storage	Increasing energy prices	Regulations and standards for energy efficiency of buildings
Barriers	ROI has still to be proven for users	Insufficient Interoperability	End-user acceptance
Impacts	Increasing demand for integrated BMS	Opportunities thanks to interoperability standard	"MS Home" (EnergyPlus for everybody)

State of the Art	Short term	Medium term	Long term	Vision
Quality of service: Some self-diagnosis systems exist in the HVAC and lighting domains. Some sensors can also monitor their own functioning, and communication protocols also include error detection in the data frame. For communication protocols, many open or proprietary de facto standards co-exist with different properties.	Enable diagnosis of EE-related building components (both "passive" ones like windows and active systems) has to be developed. Develop transmission protocols that satisfy specific ICT4EEB requirements (in terms of reliability, security, privacy…).	Generalize diagnosis of EE-related building components through the embedding of sensors in the components. Develop self-diagnosis abilities of sensors and integrate them in the sensors themselves. Develop a common shared standard of ICT4EEB-oriented communication protocol.	Develop BMS that will be fully auto-controlled and auto-monitored, discovering their own malfunctions. Achieve WSN that will be autonomous in their energy supply.	The future buildings, along with their components, equipments, and their environment will communicate and be able to provide information on their status ubiquitously. This real-time available information will be interoperable via common protocols for holistic automation & control. The whole building will be supervised by intelligent systems, able to combine information from all connected devices, from the Internet or from energy service providers in order to efficiently control HVAC (heating & cooling), lighting, and hot water systems along with energy production,
Monitoring: Existing Smart Meters enable real-time electricity consumption reporting and visualization as well as bidirectional communication with Smart Grids. All needed sensors, with the required sensitivity and accuracy, are not available at reasonable cost for a large scale deployment.	Develop new kinds of sensors when necessary, and decrease costs of manufacturing. Develop Smart Meters able to measure, record and visualize all kinds of energy consumption.	Make Smart Meters interoperate for the build-up of Smart Meter networks at district level. Embed more intelligence in sensors in order to perform a first level data analysis locally.	Tightly and securely integrate Smart Grids and Smart Buildings through Smart Meters, allowing the Smart Grid intelligence to directly control home appliances. Extend and distribute embedded intelligence to manage EE issues locally.	

Wireless sensor networks: Some “Plug & Play” sensors already exist, whose features can be automatically taken into account by WSN-based BMS to optimize control of the related actuators.	Improve sensors in terms of reliability, sensitivity, maintenance, testing and remote diagnosis, and communication abilities. Reduce energy consumption of WSN. Identify possible negative side-effects associated to WSN.	Define standardized roles and services for sensors and actuators to allow plug-and-play of new devices and self-(re)configuration of sensor networks. Allow WSN to support change of topology for network optimization. Develop powerful embedded OS that can provide more real-time functionalities.	Achieve completely autonomous sensors in terms of energy supply thanks to advanced energy harvesting technologies. Integrate several functions (light, temperature, air quality…) in a given sensor to reduce the number of necessary sensors. Integrate autonomous sensors in building components (windows, walls…) from the beginning of the construction process.	storage and consumption devices inside the building, taking into account the users' needs and wishes.
Automation & control: Existing automation and control algorithms are most often restricted to sub-systems (heating, light, ventilation, µ-generation…), independent from each other, and hard-coded in the devices with little possibility to update or modify them by a centralized control instance.	Develop holistic control strategies that integrate all building dimensions, and develop a common conceptual framework for interoperability with the definition of a relevant set of services for sensors/actuators. Take user activities and building usage into account. Implement predictive control by considering weather forecast. Address all BMS components for predictive maintenance.	Design new holistic control strategies by simulation. Integrate simulation tools in BMS to optimize control strategy in real-time.	Introduce self-learning features in control algorithms to adapt to the user’s preferences, the building age, and the possible change in the building environment. Allow control algorithms to suggest changes in the WSN (need of new sensors, disabling of existing ones…).	

2.2.1 Automation and Control

State of the art

Today, the mathematical foundations for the control of complex systems exist (neuronal networks, distributed intelligence, local agents…). Of course, buildings are "complicated"; however, they might be less complicated than nuclear power plants, large boats, factories…

This does not mean that there is no more R&D to do in order to adapt existing automation and control know-how to a smart use for EEB. Indeed, for buildings exist of course already automation and control algorithms that include for some of them even functionalities for predictive maintenance. But they are, for the large majorities of cases

- Independent for each building dimension: heating, light, ventilation, air conditioning, µ-generation and corresponding storage systems…
- Hard-coded in the device: it is not possible to update or to modify them by a central control instance

Short term RTD priorities

So, in order to make the next step, it is first of all necessary to develop concrete control strategies that link all building dimensions (HVAC, lighting, energy production and storage…) between them and provide a holistic EE approach at level of the whole building.

To implement such strategies, even when the systems come from different manufacturers, it is necessary to lay in a conceptual way the foundations for more interoperability by, for example, defining modular and scalable system architecture for monitoring, diagnosis and control tools and their interaction and interfaces. We need moreover a commonly shared model that clearly defines roles (one for each kind of device) to which belongs a given set of APIs / services (SOA approach). This kind of work will guarantee that new devices that will emerge in the coming years, like innovative energy-efficient lighting systems or multi-functional dynamic glazing, can be integrated without further problems in the existing algorithms.

The next generation of automation and control algorithms should also take user activities and building usage into account. Weather forecast is also an important element and should be considered for predictive (and not only reactive) control.

Finally, these algorithms must not only manage the building's energy but also the components of the BMS, like for example filters of HVAC devices, in order to provide predictive maintenance functionalities, important for overall ROI considerations, especially in a professional context.

Medium term RTD priorities

Once a first set of holistic control strategies have been developed, each one for a given building and behaviour type, and once simulation tools integrate all building dimensions in a satisfying way, simulations might be used to develop new control strategies.

In a first step, simulation might only be used to improve design during development of IIC systems. In a second time, simulation tools might be directly integrated in BMS, thus helping to develop each day, in real-time, the optimized control strategy, dependant on the most accurate weather forecast available and on the forecasted activity type of the inhabitants. This will tremendously improve the quality of predictive control.

Long term RTD priorities

Since each building is different, use habits are changing during the lifespan of a given building, and holistic control algorithms taking into account several building dimensions might be rather difficult to customize, it is essential that control algorithms become self-learning on the long term.

Thus, they will have to adapt themselves to:
- The current preferences of the current habitant of a given room / building
- The age of the building that itself changes
- The changing surroundings, as for example a new neighbour whose house hides the sun

This self-learning process can have three kinds of input:
- Simulations that the system does on its own
  - Observations of the system where it discovers itself that there is no use anymore to open the curtain of a given window in order to heat since the new neighbour’s house hides the sun
  - Manual input

If this self-learning system does not manage to reach a stable configuration (i.e. a situation where manual input is not necessary to satisfy the current habitant) the system might lack the necessary information (the necessary sensor) or the necessary lever (=actuator) in order to satisfy the current habitant. So the next step (and certainly not the last) might be control algorithms that suggest:
- Installation of new sensors / actuators for a given room utilisation
- Disabling of an existing sensor that is not relevant any more to improve
  - System consumption
  - Computation time

and detect through the same mechanism that a given existing sensor / actuator is not working well.

Control algorithms would thus become:
- Actors of IIC infrastructure optimization
- Diagnosis tools of a given IIC infrastructure

2.2.2 Monitoring

> ***You can’t fix what you can’t precisely measure***
>
> Robert WEST, CEO, Echelon

State of the art

The existing Smart Meters enable real-time electricity consumption reporting and visualization as well as bidirectional communication with the Smart Grid.

Concerning instrumentation in general, many sensors are available to monitor the building conditions or usage from an EE point of view. The most commonly used are for water, electricity, or gas metering. Temperature, wind, humidity, air quality, brightness and luminosity sensors are also available. But depending on the envisaged application, specific sensors with given accuracy are required, that are not still available or at least affordable for a large scale deployment (e.g. convective heat flux sensor).

Short term RTD priorities

Thus, progress has to be made to develop new kinds of sensors when necessary and, even more important, to decrease costs of manufacturing of the existing range of sensors.

In order to optimize workload of gas pipelines and/or of pipelines for district heating, dynamic prices not only for electricity but also for heat / cold / domestic gas will be introduced. This requires, from a technological standpoint, generalized smart meters able to measure, record and visualize all kinds of energy consumption.

Medium term RTD priorities

On a medium term, we have to care about interoperability between Smart Meters; interoperability allowing the constitution of Smart Meter networks in a whole district. These networks will have their own intelligence (at district level) and allow thus the implementation of µ-Grids and of optimized district heating systems.

In parallel, in order to reduce data flow from the growing number of sensors, we need to embed more and more intelligence on the sensors themselves in order to perform a first level data analysis locally. This will allow sending only “relevant” data from the sensor to the central instance of intelligence.

Long term RTD priorities

In a long term perspective, Smart Meters might overcome the barrier between Smart Grid and Smart Building by:

- Integrating sophisticated encoding algorithms guaranteeing data privacy for the private individual
- While allowing in the same time the Smart Grid intelligence to control directly the Smart appliances of a given household

In parallel, the embedded intelligence has to evolve and to integrate more and more control functionality locally (through implementation of concepts of distributed intelligence) so as to manage some EE issues locally, at the room level, by the “community” of all instruments located in a given room / responsible for a given room.

2.2.3 Quality of Service

Two RTD topics are covered by the sub-category Quality of Service:

- Improved diagnostics
- Secure communications

a) Improved diagnostics

Diagnostic of IIC systems cover two main issues:

- The first one is related to the diagnosis on building components functioning (similarly to self-diagnosis function in cars, e.g. for the lighting or air-bag system)
- The second one is related to the monitoring of the functioning of the sensors themselves, as well as other ICT devices (including communication network, actuators, control software, etc.). This functionality relies on self-detection circuits.

State of the art

In the HVAC or lighting domain, self-diagnosis systems, which can even use other sensors than those required for the control functionality, already exist for some building equipments. Gas sensors can for example detect a gas leak in a boiler system or production of CO resulting from incomplete combustion.

The functioning of sensors themselves can be monitored to a certain extent. Sensors can control the load of their battery and send a warning in case of low level. Communication protocols also include features to detect errors in the data frame sent by sensors.

Short term RTD priorities

Progress has to be made in the monitoring of the building components which are most important for EE. We need such sensors even for some “passive” building components (does the wall / door / window fulfil its mission as a wall / door / window?) and for the building functions like HVAC, µ-generation of electricity, … in order to react quickly in case of malfunction and prevent energy waste.

For maintenance relevant devices, this kind of sensors also provide precious information to be used for predictive maintenance scenarios.

Medium term RTD priorities

This diagnosis of building components and devices will be generalized since sensors will be more intimately integrated in the component / device itself from the manufacturing process, for example by embedded nano-sensor technologies.

In parallel, self-diagnosis abilities of sensors must be progressively developed and integrated in the sensors themselves.

Long term RTD priorities

Thus, on the long run, the BMS will be auto-controlled and auto-monitored, as a part of the building, discovering its own malfunctions.

b) Secure communications

> ***The rogue next door shouldn’t be able to pirate my BMS and make me freeze***
> Raymond FOURNIER, Responsible Smart Building, CEA

To link together all kind of domestic appliances, sensors, actuators, energy generating and storage devices… we need of course a communication technology that is

- Reliable
- Secure, so that no third-party can enter the system
  - Neither to gather data (⇒ respect of data privacy)
  - Nor to pilot my house in an unwished manner
- EE itself.

State of the art

About ~100 different “standards” exist currently on communication protocols. The most wide-spread ones use LON/BACnet and KNX.

Besides these wide-spread standards, a huge number of “new” standards exist (NFC, Bluetooth, Wi-Fi, RFID, ZigBee, …) and even legacy solutions have become de facto “standards” in a certain kind of way (X2D, io-homecontrol, …).

Short term RTD priorities

The first priority of the RTD community is to develop transmission protocols that satisfy the specific ICT4EEB requirements in terms of reliability, security, privacy, data consistency, and transmission rate for wired (all kinds, including PLC) and wireless transmissions.

Medium term RTD priorities

Once the technological feasibility is proven, a commonly shared standard has to be found.

Long term RTD priorities

On the long term, communication standards must themselves become EE to allow WSNs to be autonomous in their energy supply. This includes use of optimized data formats, energy aware routing…

2.2.4 Wireless Sensor Networks

State of the art

Inside the range of products of given companies, first plug-and-play sensors exists, that identify themselves via by example a ZigBee data transmission and where a central BMS takes these new information into account in order to optimize control of the related actuators.

Elements for progress are presented in the following but improvements will also come from improved communications (see also the chapter on Secure Communications).

Short term RTD priorities

In order to go further and to be able to integrate products / systems from different manufacturers, standards, especially for data transmission and format have to be defined.

Concerning the sensor itself, continuous improvements must be done to

- increase sensor reliability,
- diminish maintenance problems,
- allow easy testing and remote diagnosis,
- increase sensor sensitivity,
- improve sensor's communication abilities (Phy/Mac interface, encoding, …).

In order to reduce energy consumption from the WSN itself and to limit the battery change frequency, and allow later the possibility of autonomous supply:

- Improvements have to be made on energy efficient wireless communication reducing the frequency and amount of information to be transmitted (e.g. with energy aware routing).
- Operating systems must provide low consuming APIs used to put the sensor hardware into a stand-by mode and allow it to wake-up only when some threshold has been reached on its inputs.

Besides, complementary RTD must be done to clearly identify if there is any negative side-effects associated to electromagnetic radiation of WSN. Indeed, an increasing part of the population is very aware of this issue, crucial for acceptance.

Medium term RTD priorities

Progress should be made to allow plug-and-play of new sensors and self-(re-)configuration of sensor networks in case of addition or removal. To that purpose, a set of standardized roles and services (APIs) for sensors and actuators will have to be defined and shared.

Concerning network optimization, future WSN have to be designed to take the best of different topologies (meshed, tree, star, etc.) enabling potentially to dynamically switch between different network topologies, by example in function of the battery charge level of the nodes (that can be the sensors themselves).

Embedded multi-tasking OS will need to evolve to provide more real-time functionalities in order to meet different real-time application requirements. Future platforms will have to support automatic management, optimizing network longevity, and distributed programming. Because of their specific hardware and different functionalities, sensors will require powerful OS that handles task scheduling, radio communication, time, I/O processing, and middleware services and that will include time synchronization, message routing with data aggregation, localization and standard abstractions (such as UNIX) and support common programming language (like C).

Long term RTD priorities

Sensors in WSN have to become completely autonomous in terms of energy supply. They will then rely on energy harvesting via a mix of technologies like vibration, temperature gradients, electromagnetic waves, and light via PV. Since these sources are intermittent, autonomous wireless sensors will also need high performing rechargeable batteries.

At this stage, we will also have to reach for packaged sensors, thus to integrate several functions (light, temperature, pressure, noise, humidity, air quality – in terms of CO_2 but also in terms of VOCs or other polluting agents – occupancy, activity, …) in a single sensor in order to reduce the total number of necessary sensors.

The last step we present here is the integration of autonomous sensors in windows, walls, doors…, from the beginning of the building construction.

2.3 User awareness & decision support

Key research topics

Performance management

Research on this topic will contribute to fine-tune building performance indicators (accuracy, comprehensiveness, ease of use), and create tools to give support to the end-user for performance improvement (decision support).

Visualisation of energy use

Ongoing research projects on this topic need to be further continued, especially through multidisciplinary pilot projects (involving experts in mobility, user interfaces, sociologists, designers, etc.) so as to work on energy efficiency incentives and adequate energy visualisation presentations.

Behavioural change by real-time pricing

New technologies for energy metering and local energy generation will considerably change the customer relationship with the energy providers. The implied change on regulation and business models offer new perspectives and need to be accompanied by new adapted ICT infrastructures.

Vision

ICT supports understanding, capturing and formalising customer/client anticipations into requirements, conveying them to all stakeholders and validating compliance. The impact of ICT on EE is well understood via model-based evidence. Standardised methods and indicators are available for assessing and benchmarking the energy performance of buildings, systems and components. Performance audits, labelling and continuous commissioning are supported by recorded data of real time performance.

Intuitive feedback is given to users and operators on real time energy consumption and pricing, enabling them to optimise the control of the building and their usage behaviour.

Drivers

The main drivers are increasing user awareness, regulatory requirements and the shift towards performance based contracts. All these increase emphasis on whole life time performance of buildings.

Barriers

Barriers include: the traditional contractual practice with focus on the initial investment cost without considering energy performance; lacking financial mechanisms and business models to support investments in energy efficiency; Unawareness and also lack of evidence of the actual impact of ICT solutions and other investments for energy efficiency.

Impacts

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. This will create new business opportunities to utilities, financial services (e.g. ESCOs), and suppliers of software and devices (e.g. smart meters and energy awareness displays).

Scenarios

A. Solutions for cost and energy consumption display (during operation phase): in the next generation of buildings, the dweller / occupant will be empowered thanks to accurate cost and energy consumption information display, either centralised on global monitoring dashboards, or decentralized through individual meters on each energy equipment / household appliance.

B. Performance monitoring and decision support applications: The dweller will be able to compare its detailed energy consumption history to other users with similar profiles, in order to estimate its performance and find ways to improve it. Moreover, the energy displays will include functionalities for decision support aiming at proposing to the occupant manual and simple actions to optimize energy consumption. When linked to realistic simulation models, the display will also indicate how much energy will be saved when performing the proposed action. This bridge between operation and simulation data will contribute to improve simultaneously simulation models & decision support engines.

C. Standards based energy performance calculation software: The real-time consumption data information will be calculated taking into account the holistic view of the building (relative performance), and also considering grey energy. Once these energy calculations processes are standardized, it will be possible to include it in new and more reliable energy efficient buildings certifications.

Related roadmaps/SRAs

ECTP SRA [41] defines ”meeting user/client requirements” as one of its 3 high level priorities. Identified reseach topics related to users include e.g.: visualization, virtual reality and communication tools, based on advanced ICT systems and using shared integrated data models, enabling a “value” assessment of the built environment asset to take place in many dimensions: energy consumption, visual impact, functionality, internal environmental quality, safety, security, flexibility, operating costs and expected lifetime, etc..

SmartGrids [38] will empower users by providing information to them about their consumption and enabling them to become active participants in energy trading. The end-users (customers) are seen as prime “movers” in the evolution towards SmartGrids.

Table 4. Roadmap for user awareness & decision support

Drivers	Regulations, awareness, cost reduction	New business opportunities based on energy savings	Whole life performance of buildings
Barriers	Contractual practice based on initial investment cost	Lack of evidence to support investments into EE	
Impacts	Inreased EE through user empowerment	EE and financial services	Life cycle optimised buildings. Users as active players in energy market.

State of the Art	Short term	Medium term	Long term	Vision
Management of performance requirements: Currently only basic and aggregated energy monitoring indicators, lack of decision support functionalities	• Benchmarking tools to assess theoretical models towards data from real operations • Establishment of a performance track record database, including accurate building specifications	• Communities for sharing and ranking energy information • Data security privacy • Decision-support tools for energy trade between buildings/parts of buildings	• Energy efficient buildings certification	Energy efficiency of buildings will be ensured by established models, methods and tools for: understanding customer/client perceived values; capturing and formalising requirements; conveying the requirements to all stakeholders; assessing the estimated or actual performance and expressing it with verifiable performance indicators; communicating/visualising the performance for decision making by the involved stakeholders.
Visualisation of energy usage: Some emerging technologies but need for further experimentation to assess actual impact, and need for more research to fine-tune information presentation and content.	• User motivation and incentives • Interfaces for energy display • Energy awareness impact on user behaviour	• Integrated energy visualisation tools • Integrated information on grey energy	• Training sessions on energy awareness • Decision support for long-term “lifestyle” strategy	
Behavioural change by real-time pricing tariffs: Basic existing systems that can be easily improved thanks to facilitated communication between consumers and energy providers	• Tools for adjusting consumption to real-time pricing tariffs	• Adaptive energy contracts	• Personal energy rationing strategies	

2.3.1 Performance management

State of the art

For improved energy management of buildings, the most detailed level of information is required. Current buildings are often equipped with monitoring systems offering basic indicators (e.g. global consumption at building level), and they lack decision support functionalities. The main envisaged ways of progress on this topic are to increase information granularity, and to add features for benchmarking, decision support, and optimization.

Short term RTD priorities

Benchmarking tools to assess theoretical models towards data from real operations

Medium and large scale research projects should work to establish a new generation of performance management tools that integrate data from theoretical simulation models, and weigh it against the building real-time data monitoring. Together with the usual real-time performance indicators, these tools should provide decision support and advice for energy efficiency improvement according to optimal simulated reference patterns. More generally, these research actions will contribute to a seamless integration of tools and processes between building design and operational phases.

Establishment of a performance track record database, including accurate building specifications

This research action is to establish a knowledge base that will record and centralize energy performance data of exemplary buildings. Each record will include comprehensive information about the building specifications and usage. This knowledge base will then serve as reference data to crosscheck results from building simulation tools, but also as a calibration / performance objective for future real constructions.

Medium term RTD priorities

Communities for sharing and ranking energy information

Comparable to the recent growth of social networks, it is foreseen that energy performance data will become available through online communities, and therefore offer a potential for new added-value services. Several medium to large research projects should be launched to prototype these new services enabled by the networking of energy information. Each service should be then trialled within a representative users' territory.

Among all the envisaged scenarios, a first service could be a ranking platform of "energy consumers" with similar profiles. By comparing the performance data, the platform would provide advice for efficiency improvement as well as incentives (e.g. money savings perspective) to stimulate their implementation. By "energy consumers", it is implicitly meant that different scales can be investigated: end-users (occupants), buildings, districts, etc.

Data security privacy

This research topic closely relates to the previous one, since the online availability of personal energy information raises privacy issues. Dedicated research actions should address information ownership issues, screen attackers profiles and potential risks. It should then elaborate and propose appropriate strategies (technical, regulation, etc.) – or in case adapt strategies developed in other application fields - to prevent these risks, in collaboration with the service providers.

Decision-support tools for energy trade between buildings/parts of buildings

An in-depth analysis of energy consumptions and profiles should lead to the identification of energy trade strategies – therefore leading to solutions improving performance management at a macro-level (whole complex building, groups of buildings, energy-efficient districts, etc.). Research should focus on the identification of matching combinations of energy profiles (shifted energy needs and productions), allowing energy cooperation. Energy storage is a connected topic and therefore experts in this field could be associated to the research.

Strategies can be envisaged at the (whole) building level or district level, and therefore will provide feedback to building designers and local planners.

Long term RTD priorities

Energy efficient buildings certification

Long-term research is needed to create European labels for characterization (and further evaluation) of energy-efficient buildings. The labels should take into account the whole complexity of the building, and should consider its whole lifecycle. It should also take a comprehensive view on the energy consideration, i.e integrating (and potentially differentiating information related to primary energy and final energy, integrating grey energy (to produce the energy) and consumed energy (power requirement), etc. Therefore the certification should be not only relying on the building equipment and design, but also on the verification of real-time performance on operation. Hence, ICT tools need to be developed to automate these future certification processes, in a flexible enough way so as to adapt then to country specificities.

In the meantime, there is constantly a risk to influence comfort when working on energy efficiency optimization, and therefore it would be rational that an energy efficient building certification ensures that a decent comfort level is preserved. Fundamental research actions should be started on the definition of a well-being / comfort rating, which could be then integrated in the above mentioned tools.

2.3.2 Visualisation of energy use

State of the art

Some research projects are already working on different technologies for energy visualisation, and it is agreed that they can have an impact on energy consumptions. However, there is still a need for further experimentation to analyze the actual impact on energy reduction. Further work related to information presentation and content is also needed.

Short term RTD priorities

User motivation and incentives

Small scale research projects are needed for a classification of incentives & triggers per stakeholders in different contexts (e.g. residential, office, etc.). This research should be conducted through interviews of selected representatives and using panellist methods. The main expected outcome is the best content or package of information needed per stakeholder for energy-efficiency awareness and stimulation.

Interfaces for energy display

Medium and large scale research projects are needed to define the most appropriate way to present the energy information. One of the axis of the research is to fine-tune the metrics and units (e.g. kWh versus Euros) used in traditional interfaces (e.g. web based), as well as the information delivery process (e.g. information push). A second aspect is to prototype innovative interfaces and display for energy visualisation; experts in design, ubiquitous yet unobtrusive interfaces, and mobility aspects should all together create the specifications for more intuitive and natural energy displays for buildings.

Energy awareness impact on user behaviour

Pilot projects enabled by the latest energy visualisation techniques should contribute to assess the actual impact of energy visualisation on user behaviour – integrating as well the users' feedback with respect to these visualisation techniques and interfaces. Using methodologies similar to clinical studies (e.g. placebo groups), the pilots will directly involve end-users sorted by profiles (age, activity, type of building, etc.). The investigation should help to determine the optimal strategies to obtain long-lasting eco- behaviours.

Medium term RTD priorities

Integrated energy visualisation tools

Cross-sectors research projects should be launched to create a new generation of integrated energy visualisation tools that encompass energy consumed in a comprehensive way (home, travel, office, etc…). These new tools would allow proactive (simulation) and reactive (real-time analysis) functionalities for a comprehensive evaluation of individual carbon footprints, showing the balance between the different consumption uses.

Integrated information on grey energy

Medium to long term research is needed to establish "grey energy" indicators, taking into account not only the power requirement, but considering also energy production, transport, storage, as well as the disposal of products used. This research should lead to more accurate energy visualisations, and would of course impact the design choices and decisions for future services.

Long term RTD priorities

Training sessions on energy awareness

As a long term objective and based on the findings from the above mentioned research actions, training courses on energy awareness could be developed and proposed to all stakeholders in the field of construction. These training would include concrete good practices and guidelines for e.g. setting up eco-responsible campaigns in companies. To facilitate a wide knowledge dissemination, all technologies such as eLearning, eCourses or learning games can be envisaged.

Decision support for long-term "lifestyle" strategy

The long-term generation of user awareness tools could incorporate advanced simulation features to evaluate the interest of radical changes in lifestyle or way of working. Based on the accurate knowledge of current energy consumptions, these tools could for instance assess validity of telecommuting (teleworking) strategies, building relocation, new manufacturing processes, etc. Societal experts need to be associated to this research, as their insight on work & personal lifestyle major trends is essential.

2.3.3 Behavioural change by real-time pricing

State of the art

Very basic systems such as light signals exist to inform the customer of the current energy tariff. More sophisticated solutions can easily be developed upon the same concept, thanks to a facilitated and more regular information exchange between energy consumers and energy providers. It is however agreed that the deployment of these new concepts will go together with appropriate driving schemes at council level with incentives (e.g. taxes, stamp duty credit, etc.)

Short term RTD priorities

Tools for adjusting consumption to real-time pricing tariffs

It is wise to use pricing as one of the main incentives for stimulating eco-behaviours. Based on the latest technologies for accurate and flexible energy metering and remote communication with the energy provider, short term research actions can be performed to improve the offer: decision support algorithms to advise the end-user to consume at the cheapest time, semi-automated scheduling systems connected to heavy consuming appliances, simulation programs allowing the customer to select a best-fitting energy contract according to personal energy consumption history, etc.

Medium term RTD priorities

Adaptive energy contracts

From the energy provider point of view, medium-term research actions are possible to build a new generation of energy contracts for customers, with flexible and personalized tariffs. New models and (ICT tools implementing and managing those models) will be needed to adapt in a fair way the contract to the customer behaviour and eco-responsibility. These models should naturally include local generation and energy trading scenarios.

Long term RTD priorities

Personal energy rationing strategies

In some critical situations, or when vital energy efficiency efforts are needed (to ensure for instance stability of the grid, and avoid energy blackout), energy rationing strategies (limited energy credits allocated per entity) can be fully justified. Long-term research should lead to new energy systems incorporating features for putting these strategies in place for a temporary period.

2.4 Energy management & trading

Key research topics

This category, Energy Management and Trading, includes the RTD's development of methodologies and tools for efficient energy management on all levels (e.g. urban, district, grid, building, room, area).

Figure 9 below presents the harmonised specification of subcategories, jointly developed by WP2, WP3, and WP4. The first identified research challenge results from the distributed generation of Energy. Since most generation sources are dedicated to renewable energy the generation capacity is less stable and continuous compared to conventional, central sources for energy generation. Therefore, advanced knowledge about the energy demand in local distribution grids but also in an overall supply grid is critical for the load-balancing and the load prediction.

The second identified research challenge emphasises on the demand / supply-prediction on all relevant levels. It aims to optimise the deployment of renewable sources, to minimise the environmental impact and to optimise the financial benefits. Therefore, (near) real-time response to changes in the demand-supply capacity are required.

Precise information about demand-supply capacities is also important to support advanced energy trading. In the future, energy trading will be expanded with functionalities of "Local Storage Management", such as seasonal storages, interaction with eCars, passive storage (e.g. PCM), etc.

The third identified research challenge focuses on the improvement of tools and underpinning methodologies for Network Planning and Plug&Play scalable integration of microgeneration & storage.

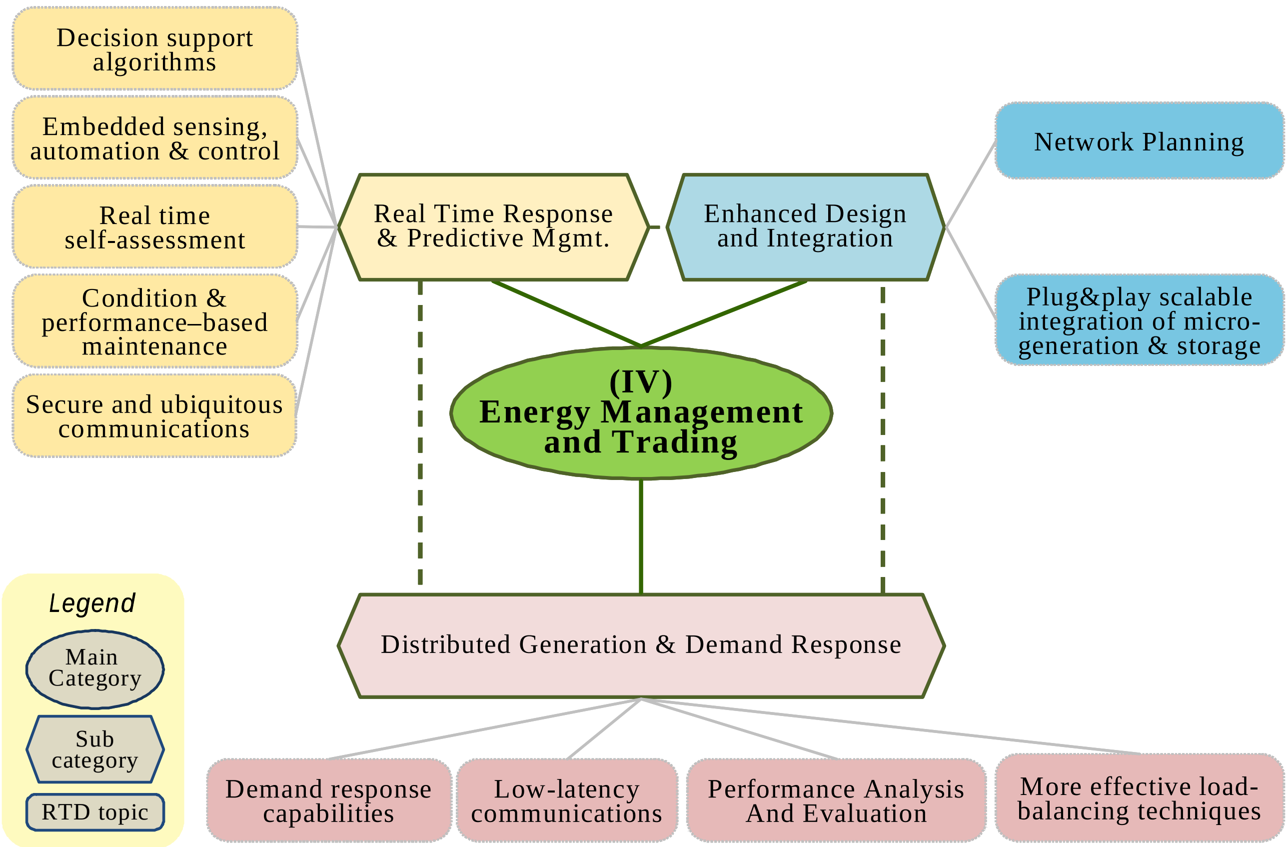

Figure 9. Energy Management and Trading

Real-time response and Predictive Management:

Since in case of extended renewable energy generation the capacity in energy-grids is will substantially more depend on weather conditions the capabilities for load-balancing must be extended. This can be achieved through improved capabilities to predict the demand/supply capacity and the capability to quickly adjust demand and (local) supply to the current generation capacity (real-time response). The following chapter describes the research challenges in this area:

Embedded sensing, automation and control: research should focus on:

- Wireless Hardware Platforms, since wireless sensors and actuators can be easier installed in existing buildings. Their application will lead to cost savings for wiring.
- Further research is required focusing on energy harvesting (to ensure "long term, maintenance free" energy supply). Packaging needs to be customised to the requirements of the construction sector to ensure easy, "aesthetic" installation and optimal signal propagation within buildings.
- Innovative firmware needs to be developed to ensure "energy-optimal" operation of wireless sensors, meters and actuators leading to minimised maintenance costs.

Secure, ubiquitous communications: research should focus on:

- Communications protocols must ensure that sensed and metered data can be managed in a secure way. It should be impossible to analyse behavioural patterns of individual tenants or building users.
- Further research is required to improve the "self-adaptability" of networks. The requirement for network management should be minimised. Meshed network topologies are recommended.
- Standardised data exchange protocols are required to ensure market liberalisation and prohibit the dependency on specific vendor protocols.
- Research is required to optimise network traffic by introducing a clear separation of network traffic on the appropriate systems level (e.g. on apartment, building, or district grid level).
- Decision Support Algorithms: research in this area deliver the right level of software support for the development of decentralised metering and control;
- Real Time Self Assessment: developing the availability of consumption data on "item level", allowing energy consumption overview in real-time;
- Condition and Performance-based maintenance: identification of the most efficient maintenance strategies and business processes models for it based on the real-time and stored data from BMS;

Enhanced Design and Integration:

These researches suppose to develop simplified interconnection standards, two-way power flow capabilities and more effective load balancing techniques to allow distributed generation and energy storage to be incorporated seamlessly into the transmission and distribution network, i.e.:

- Network Planning: projects stimulating "Knowledge Transfer" amongst the "Energy Sector" and the "Construction Sector" to enable representatives from both sectors to better understand the "advanced requirements" for interface design which will impact the overall network planning;
- Plug and Play scalable integration of micro-generation and storage: research focused on the development of dedicated storage capacities to optimise the functionality of single systems

(e.g. the development of seasonal storages for solar heating), as well as directed to develop an integrated management of storage capacities in buildings.

Distributed Generation and Demand Response:

This sub-category have to contain those RTDs working on development and implementation of more effective energy load-balancing techniques, energy network performance analysis and evaluation, identification and improvement of the energy demand response capabilities, efficient stipulation of the low-latency communications.

- Demand Response Capabilities: development of integrated control for local energy generation and demand in combination with intelligent control of energy storage capacities to establish additional "demand response capabilities" on "local" level;
- Low-latency communications: research would provide communication between the generation devices, the control systems, the "consumers" and potential storage devices for efficient control over distributed energy;
- Load Balancing Techniques: So far, energy was required to operate buildings. Past and recent research has focused on the integration of additional, single renewable energy sources into the buildings' energy system. Some work has been done to develop advanced control devices for photovoltaic systems;
- Performance Analysis and Evaluation: research focus on the adaptation of methodologies for multi-dimensional analysis and evaluation of the needs for the energy in buildings; energy performance data analysis (e.g. long-term measurement, geographical influence, seasonal influence, etc.).

Vision

Through the integration of multiple (renewable) energy sources into the built environment the Energy Management Process will become more complex than in the past.

> **Vision 1:** The availability of tools for advanced Supply-Demand Data Management is becoming an essential requirement. Research in the area of "Multi-Dimensional Information Management" is required to develop appropriate hardware-software platforms that allow the flexible, multi-dimensional compilation, storage, analysis of performance data from buildings, local and global generation capacities.

Energy Management will consider generation and demand capacities. Additionally, numerous, multi-scale storage capacities will be added to the Energy Networks.

> **Vision 2:** Decision Support Tools need to be developed, assisting tenants, building and network operators in managing the consistent interaction of the various "thinks", "sources", and "buffers" in an Energy Network on building, district, or global level.

Since the integration of renewable, distributed generation capacities leads to more complex technical systems, the availability of enhanced design and integration tools is required.

> **Vision 3:** Network planning tools must be capable to easily integrate basic model data from other design tools using standardised interfaces and web-services. Furthermore, network design tools must be capable to integrate energy systems driven by different energy sources. Finally, we envisage that design systems support systems re-engineering by acquiring technical data from existing system components (e.g. boilers) and developing "semi-automatically" schematics for energy systems.

Since renewable energy sources do not provide a constant supply capacity, improved mechanisms for load balancing, performance analysis, and demand response capabilities are required.

Vision 4: Systems and components must be equipped with intelligent control features. It is envisaged that innovative Energy Systems allow for multi-level control; i.e. that certain control functionality will be processed autonomously on “zone level”, other control functionality will be processed autonomously on “building level”, and finally that the operation mode of energy-consuming devices can be controlled by external sources depending on the overall supply capacity (including storage capacity), the resulting energy prices.

Drivers

The major driver for R&D activities focusing on Energy Management and Trading is the requirement to reduce the Carbon Footprint of the Built Environment. This general requirement is underpinned by European and National Legislation, such as the European Energy Services Directive (amongst many others). Furthermore, National legislation or National Programmes request or stimulate the introduction of smart meter technology. Finally, these activities are complemented by National programmes to stimulate the installation of renewable energy systems and passive and active building technologies contributing to energy savings.

Conclusion: The first major driver for R&D in Energy Management and Trading is the increasing number of available (renewable) energy sources and the related National, European, and International legislation.

The second major driver for R&D activities focusing on Energy Management and Trading is the introduction of new, holistic, integrated business models for Energy Management and Trading.

(1) PPP-type contracts: In case of Public-Private-Partnerships the “risk of ownership” is transferred from the user of the building to the PPP-members. Energy costs are a substantial part of the operational costs. The ability to decide about the efficient usage of an “Energy Mix” from renewable sources (associated to the building) and other external sources will substantially influence the operational costs and will thus become a “key success factor”.

(2) ESCO: In case of Energy Service COmpanies the underlying business model is based on the assumption that the “Total Energy Service Provider” shares the savings generated from the optimised Energy Management and related Value Added Services (e.g. performance based maintenance of systems and components) with the owner or tenant of the building. The capability to participate in flexible “trading” with multiple energy providers (gas, electricity, others) is an essential enabler for the holistic optimisation of selling, buying or storing energy. Furthermore, the capability to precisely monitor and analyse the building performance and the related energy consumption is a pre-requisite for offering further “Value-Added Services” to ESCO customers.

Barriers

<u>Privacy:</u> Advanced Energy Management and Trading is based on the assumption that consumption and performance data are compiled, stored and analysed in a fine granularity. The availability of detailed data tracking the usage and performance of heating, lighting and appliances inherits the risk that this data can be misused by third parties to analyse the “user behaviour” in an inappropriate way, interfering with the privacy of building tenants.

<u>Restricted, non-standardised data-exchange protocols:</u> It is essential to introduce standardised formats and protocols for the exchange of data describing the Energy-Demand and Supply Profile of tenants. Non-standardised, provider-specific formats might negatively impact market competition and enforce customers to stay with certain, dedicated providers.

User Qualification: It is essential that platforms for Energy Management and Trading can be easily installed and operated, even by users with limited expertise and skills.

Impacts

Diversification for ICT-stakeholders: The capability of stakeholders from the ICT sector to offer holistic, integrated service platforms to offer value-added services for Energy Management and Trading along the whole value chain from the development and manufacturing of embedded sensing, automation and control hardware-software system, complemented by domain specific software tools focusing on decision support, assessment, performance analysis, intelligent control, maintenance management, network design and operation allows the ICT-stakeholders to address a broader market, to bundle services, to use synergy effect and to ensure efficiency gains.

Strengthening the Competitive Advantage of stakeholders from the Construction sector: The capability to provide an “Energy Service Platform” will enable stakeholders to expand their business towards Total Facilities Management and Life-cycle Oriented Building Management. Stakeholders will benefit from their (already existing) engineering expertise and their technical skillsets and complement their portfolio of technical-oriented service towards management and business-oriented services.

Scenarios

A. Protocols, processes, equipments and software tools enabling a real-time interaction between the building (or group of buildings) and the energy provider(s):

One potential application scenario is in the residential sector. The availability of “DYI-kits” containing a certain set of inexpensive wireless sensors and meters, and one or two active network components would allow the self-installation of a network for “Building Performance Monitoring. The package might be completed by a pre-installed piece of software allowing the reading of sensed and metered data on a local PC. When connected to either a smart meter or a DSL-modem (via an Access Point) the user could initiate the transmittance of performance and consumption profiles to a “central performance management server” of the Energy Provider.

Let’s assume the DYI-kit is designed in a modular way the functionality might be expanded in a second step by installing (wirelessly control) actuators, such as magnetic valves.

This would support a “zone based control” of the home energy network. However, this would require the implementation of a control model. Therefore, we assume that the major components of the network can provide their “technical specification” plus the knowledge about their “neighbouring components” on request to a central control component using a standardised data exchange format/protocol. This means, the system provides a self-configuration support through its re-engineering functions.

B. Smart metering for grid energy management:

Smart Meters are the “focal point” of this scenario description since they “bridge” the gap between the “internal energy management” and the “(external) distribution network”.

Smart Meters might have the capability to communicate with a central control device “behind” the meter which collects and evaluates all sensed and metered performance and consumption data. Secondly, Smart Meters do provide information about available supply capacity and the related pricing. This information is communicated and evaluated by the “control device”. The control device can decide (a) to reduce consumption by turning off or “slowing down” consumers (b) increase the consumption by increasing the performance of consumers or charging storage devices.

Finally, Smart Meters will be capable to collect “consumption profiles” from the active control component, evaluate these, and predict a “Demand Profile” This predicted demand profile is broadcasted to the network operator.

Related roadmaps/SRAs

The emphasis of this paragraph is to give an overview about related roadmaps provided outside the EU-framework to inform the reader about regional or international activities which complement the EU-activities.

- Using Financial and Market-based Mechanisms to improve Building Energy Efficiency in China” [47].
- Energy Efficiency Roadmap for India [19].
- A report by the Stockholm Environment Institute, entitled “A European Eco-efficient Economy”, providing a basis for discussions during an informal meeting of energy and environment ministers on 23–25 July 2009 [39].
- UBC Agenda 21, Action Programme 2004-2009 - Roadmap for Sustainable Baltic Cities. Adopted by the VII General Conference of the Union of the Baltic Cities, Klaipeda, 17-18 October 2003 [46].
- Energy Efficiency Technology Road Map from Bonnevill Power Administration [20].
- Better buildings through energy efficiency: A Roadmap for Europe [5].

Table 5. Roadmap for energy management & trading

<table>
<tr><td>Drivers</td><td>European and National Legislation

Increasing availability of (renewable) energy sources</td><td>Holistic, integrated business models for Energy Management and Trading
How to exploit energy data?
What value-added services are required from customers?</td><td>Requirement to reduce the Carbon Footprint of the Built Environment.</td></tr>
<tr><td>Barriers</td><td>Privacy
Who owns Energy Data?
Where and how to manage energy data?</td><td>Restricted, non-standardised data-exchange protocols
How to exchange energy data?
What is the commercial value of Energy Data?</td><td>User Qualification
What is the impact of my activities?
What “upgrades”/actions create the most sustainable impact?</td></tr>
<tr><td>Impacts</td><td>Diversification for ICT-stakeholders:</td><td>Strengthening the Competitive Advantage of stakeholders from the Construction and the ICT-sector(s)</td><td>Reduction of Energy Consumption in Buildings
Contribution towards the European Objective “20:20:20”</td></tr>
</table>

<table>
<tr><th>State of the Art</th><th>Short term</th><th colspan="4">Medium term</th><th>Long term</th><th>Vision</th></tr>
<tr><td>Building energy management:</td><td>Embedded Sensing, automation & control

Real-Time Self Assessment</td><td rowspan="3">Decision Support Algorithms</td><td rowspan="2">Performance Analysis and Evaluation</td><td rowspan="2">Secure, ubiquitous communication</td><td>Network Planning</td><td>Condition and Performance-based maintenance:</td><td rowspan="3">To support the integrated and secure operation of “cascading” energy generation, storage and consumption capacities in the best interest of all energy consumers, the environment and the overall society – using a business model that enables the beneficial operation of integrated energy infrastructure systems.</td></tr>
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2.4.1 Building as a prosumer[8]; Intelligent Building Management Systems

State of the art

To make buildings prosumers it is essential that the currently existing Building Management Systems (BMS) can easily exchange information with other technical systems[9] and with the different user groups, such as tenants, owners, network operators, etc. In other words, the BMS must be enabled to understand the “context” in which a building is operated. The context is specified by user preferences, energy tariffs, and energy services offered (e.g. maintenance offers & requests).

This means that the BMS installed must be capable to effectively represent in real-time the current situation, create awareness about energy consumed and predict future demand/overflow of energy. Systems supporting these functionalities could be named as Intelligent Building Management System (iBMS) [27].

Current systems have a very limited capability for data interpretation. In residential buildings tenants can express user preferences through thermostats and time control. In commercial buildings BMS can control set-points for CO_2 levels, lux-level and presence detection. User interaction in the later cases is limited. Simple interfaces for data representation which can be customized by the end user rarely exist.

Secondly, it is essential that the building (or more precisely the iBMS) can provide decision support within the specified context; i.e. allowing the building tenants, operators and owners to better understand the consequences of certain behavioural patterns and providing instruments to improve these behavioural patterns by achieving a higher degree of energy efficiency with none or limited impacts on the user comfort.

Current systems in residential buildings have none or very limited capability to deliver any decision support. Advanced systems for commercial buildings or in industrial settings do provide in exceptional cases decision support how to operate complex systems. However, these are “purpose built” systems, tailored for a specific use case.

Short term RTD priorities

Today there are three main short term challenges to be addressed by the research community related to iBMSs develoment:

- To integrate BAS with the Internet and enterprise applications;
- To solve the incompatibilities for the integration of Building Automation Systems (BAS) among products of different vendors;
- To find a common platform for all the different systems, architectures, protocols and devices to make streamlined integration in an iBMS (e.g. pro-active public display systems, advanced home/room/area automation systems, smart security/access control systems, fire-protection systems, lighting systems, car park management systems, etc.) .

To be successful, the iBMSs should manage building automation, energy, and other functions of buildings (e.g. security, access control, etc.) via a single software web based platform. This platform integrates different systems and devices, regardless of manufacturer or communication protocols, into a unified platform that can be easily managed and controlled in

[8] A **prosumer** is a pro-active consumer; culturally and socially aware, building a composite identity of consumer brands and *taking an active role in choosing a product or service*. This means access to more (relevant) information 24/7, a demanding task but with considerable reward. [http://www.motive.co.nz/glossary/prosumer.php]

[9] e.g. through Smart Meters as interface between buildings and distribution grids

real time over the Internet using a Web client application. Furthermore, such a platform requires a scalable architecture that fits any size/type of building in the residential, office or industrial building sectors.

This requires the incorporation of different embedded control technologies for:

Embedded Sensing, automation & control

- Sensing, transmission and storage of data from the building for further utilization through a range of sources (e.g. Building Energy Management Systems (BEMS), computers/servers networks, wireless/wired sensor networks, etc.);
- Efficient implementation and optimisation of all the services and equipment that provide services and manage energy consumption/production of the commercial and residential buildings;

Real-Time Self Assessment

- Advanced Metering Infrastructure (AMI): This refers to the measurement and collection system comprised of state-of-the-art electronic/digital Hardware (HW) and Software (SW) applications, as well as communication networks between them and data reception/management system - iBMS, and that make the information available to the building energy manager. AMI combine interval data measurement with continuously available remote communications. These systems enable measurement of detailed, time-based information and frequent collection and transmittal of such information to various system parties. [16]
- Data bases / repositories: iBMS should include databases of building energy characteristics with updated descriptions of building state, including measurements and technical specifications of every component. A knowledge database is also important to store information about the systems' energy historical records and "expert rules" defined for the decision unit of the system. The inputs come from sensors to the decision unit and by the help of current state diagnosis, knowledge, user requirements and information in the databases the best choice from the selection of optimized interventions will form the output control signals to the controllers;
- Multi-stations for Data visualization (with multi-monitor use to reflect all iBMS data if required) – while iBMS collect and archive a great amount of data which allows operators, facility managers, and energy managers to control the building and to perform activities such as monitoring for abnormal conditions, verifying environmental comfort levels, and testing new strategies to save energy;

Integrated System Platforms

- This includes the possibility for real-time monitoring, video/audio massages integration and storage, and adaptable/adjustable user interfaces providing a single, unified point of control;

Medium term RTD priorities

To meet the needs of the different stakeholders involved in the operation of buildings medium term RTD should focus on the following aspects:

Decision Support Algorithms:

- ***User feedback*** – building stakeholders and occupants are one of the main sources of feedback that can improve thermal comfort, the performance of energy management strategies, and the quality of data for offering value-added services, such as maintenance;
- ***Intelligent Building Management System*** – integrated with other systems into unified platform in order to provide:

- *Distributed Energy Resources Control* **-** is necessary to monitor and control distributed energy resources (gas, solar, etc.). Controls can range from simple remote-control on/off, to predefined schedules, to automatic triggering by events and parameters values measured by wired/wireless sensors, and controlled by ***specialised algorithms***.
- *Prediction/forecast Algorithms* for *decision support*- for the nearest future energy usage; for advanced load scheduling strategy; to avoid peak demand/high bill charges; [14]
- *Control Algorithms* - are necessary to continuously adjust the control parameters to maximize the efficiency of the system while maintaining stability. The adjustments actions based on measured data values/patterns found in a data repository.

Performance Analysis and Evaluation

- Performance Analysis and evaluation of behavioural patterns should be integrated into the iBMS to provide reports that can be used to adjust operations and scheduling to help minimize energy use, lower the peak in demand, negotiate energy contracts for more favourable terms, benchmark against stored energy data and check if systems need optimization, including continuous energy resources control;

Secure, Ubiquitous Communication

- For the communication between technical components as well as for users and FM-provider-personnel ubiquitous interfaces are required to broadcast or access system data when needed. These interfaces need to access to the building control platform preferably by wireless connection to major equipment components or by direct serial or Ethernet connection to a nearby controller;

Long term RTD priorities

To support the integrated and secure operation of "cascading" energy generation, storage and consumption capacities in the best interest of all energy consumers the following long term RTD activities are recommended:

Condition and Performance-based Maintenance

- *Fault detection and diagnosis:* Different fault detection and diagnosis methods are required in case of problems and errors occurring during different stages of a building's life cycle. In order to determine the proper functionality of the building an automated comparison of actual performance data with measured data can be used as an initial step for fault identification.
- *High-density performance measurements* of energy use can be used to detect possible problems in the system and to segregate/turn-off the faulty component and to transmit the "problem massage" to the manager/service team with explanation of what the impact is on the whole energy system of the building.

Smart, 'Plug and Play' appliances

- It is essential that appliances supporting the micro-generation or the storage of energy can be integrated into iBMS as easily as possible. "Plug-and Play" building control systems means, that the systems "speak and understand" the languages and dialects of the individual BAS-implementations and protocols. Furthermore, it must be possible to remotely control or program the operation of sub-systems and devices, switches and outlets (e.g. security system, HVAC, lighting, switch appliances on/off). It should be possible that appliances can receive signals from an iBMS/smart meter on changing electricity prices and behave in a prioritized[10] order, e.g. go into energy-saving mode, to "re-calculate" the time to finish their job; i.e. to increase or decrease energy consumption at "real time".

To summarise the characterization of buildings as prosumers the structure of a potential system architecture including the iBMS integration is presented in Figure 3 below. [27]

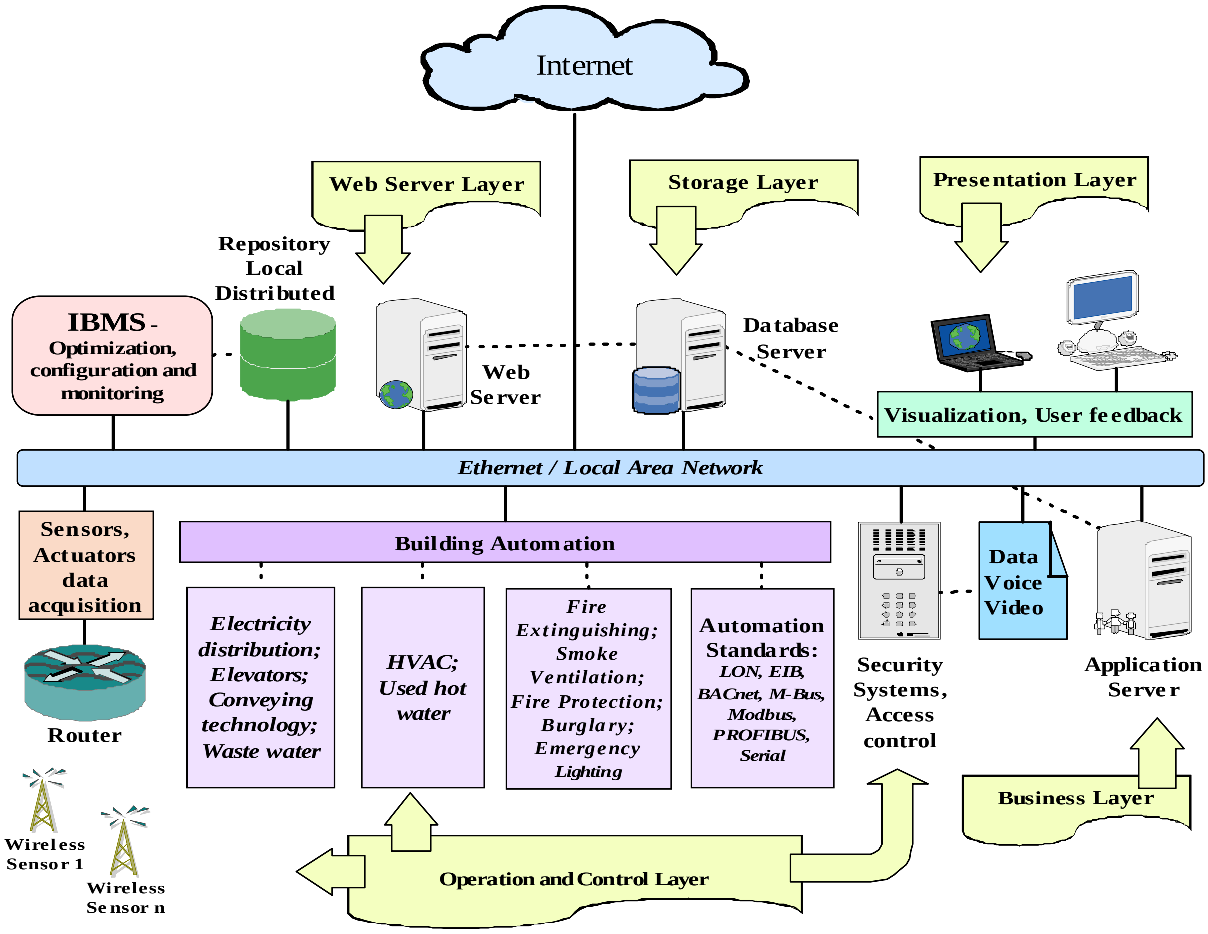

Figure 10. iBMS architecture and Building's "prosumer-functioning"

2.4.2 District Energy Management

With the increasing installation of Renewable Energy Systems on District Level in form of micro-generation devices small-scale producers can provide energy to other customer(s) via the local network (distribution grid), i.e. network operator takes energy from a small-scale producer and distributes it to other end users. The network operator could also use the overcapacity and build reserve capacity connected to the network.

However, in case of micro-generation and storage it is essential to avoid unnecessary energy losses **Error! Reference source not found.** which could be caused by long-distance transmission or energy conversion. Therefore, the establishment of District Energy Management Systems (DEM) is required to achieve coincident demand-supply capacities for electricity or thermal energy (i.e., steam, heating, or cooling) during the most of the year. District Energy Management Systems assist the operators of DEM to distribute the energy to the network of buildings and other large facilities (e.g. hospitals, hotels, apartment blocks etc., where significantly constant energy demands exist) [3]. The DEM-operator must ensure that necessary information, e.g. who lives where, which areas are most suitable for integration is

[10] Arrange activities according to pre-defined priorities

compiled, considering building types, user profiles, existing energy supply and network topology, etc.

State of the art

Currently, buildings are extended with renewable energy systems. The installation of these systems is usually stimulated through national grants. In some countries, such as in Germany, the state ensures by legislation that energy generated from renewable sources (usually electricity) can be sold for a fixed price to the main grid operator. However, a continuous, bilateral information exchange about the current and predicted supply and demand capacities on building-level and on Distribution Grid Level is neither requested nor supported.

Other countries stimulated with national legislation and state grants the introduction of Advanced Measurement Infrastructure, such as Smart Meters. It was estimated that approx. 39 mil. Smart Meters were installed in Europe at the end of 2008. Whereas Enel SpA the dominant utility in Italy has provided Smart Meters to all of its 27 mil. customers.

It is also published that almost all of the District System Operators (DSO) in Sweden had signed contracts for Advanced Metering Infrastructure solutions as of August 2007. In Finland and Denmark, the share of metering points under contract was 23 percent and 15 percent respectively according to analyst firm Berg Insight [4].

However, introduced legislation with regard to Smart Meters has been also questioned by parliaments and customer organizations. Major concerns were related to privacy issues, market liberalization and the fast changing technical specifications for these Smart Meters.

Furthermore, in the area of domestic/home networks, the commercial disputes amongst stakeholders are slowing down the “roll-out” process of these technologies. Another negative factor is a “same rate” charge for electricity at all times, so consumers have no financial incentive to run systems at off-peak times or purchase appliances that can react to demand response signals. [29]

Finally, it must be understood that District Energy Management can not be reduced to the installation of Smart Meters. Further components, such as intelligent control software, including Decision Support Algorithms to support load balancing in the network and the relevant hardware for network operation, energy storage, and flexible demand control must complement the Smart Meter Infrastructure.

Short term RTD priorities

Demand Response Capabilities

- **Supply Information provided by the Operator of DEM:** The operator should provide access to all technological as well as economical data and information of the DEM system. The breakdown for the total energy cost (e.g. heat, electricity, power) must be transparent. This should include cost for the material to run the generation and distribution facilities, facility investment costs, costs of operation and also maintenance costs. All this information must be available to the DEM-operator and on request to specified third parties. .
- **Information requested from BMS operator by DEM operator** For the building operators it is important to know how much power is available from the building/generation unit and what the energy costs are. Otherwise, DEM-operators must be informed about the demand request from building operators. This information should be stored by the data base of the iBMS, and provided on request by the building operator to specified DEM parties [15]. Furthermore, the BMS operator is able to provide information about the energy consumption - current and predicted over a certain period of time.

- **Privacy and Data Security:** It must be specified what data could be provided to third parties [29], since another important factor is the “inhomogeneous” ownership of Energy Information, which is a major reason why it could not be utilised more intensively. Sophisticated Business Models ‘bundle’ Energy Service Provision (e.g. ESCO). However, the major risk inherited in this model is the uncertainty of how to ensure a stable “return on investment”. In most contracts the problem is addressed through the negotiation of long-term contracts. However, even in these cases Energy Information is seldom used to generate new “Value-Added-Services” focusing on
  - Improved trading models and flexible tariffs;
  - Advanced component diagnosis and improved maintenance services. [25]

Medium term RTD priorities

Performance Analysis and Evaluation

- Major difficulties in planning DEM systems are poor information bases characterising the energy demand of the network potentially leading to the use of wrong parameters. In this case the usage of properly developed simulation techniques and complementing tools will provide innovative findings enabling optimal planning and control strategies for DEM systems [2], [26]. Interest in the availability of these tools is being encouraged by new national and international policies associated with reducing carbon emissions from the built environment. [31]

Long term RTD priorities

Load Balancing

- The energy (e.g. heat, electricity) co-generation units are often integrated in BMS. They are often used in BMS where an easy access to energy sources (solar, geothermal) is available and if there is a constant demand for energy during the most of the year.

  Data characterising the energy-production costs and capacity of the co-generation units should be provided to the DEM-operator. The supply side can accurately be planned and if there is less demand - the output of the energy-production unit can be adjusted or the excessive energy can be sold to utilities.

2.5 Integration technologies

Key research topics

According with the increasing complexity of the buildings and need of increasing their energy performances, day by day there will be higher demand of ICT tools that make possible:

- more agile collaboration among the multiple stakeholders that interact through the building life cycle.
- the interoperability among the increasing number of ICT tools and energy management systems that are used during building life cycle for the own building design and operation (architects, promoters, users…)and its relation with external stakeholeders (utilities, local authorities…).
- sharing the knowledge that is generated during buildings life cycle.
- reducing the energy demand of the ICT systems.

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

- **Process integration**, which addresses RTD needs in relation with collaboration support tools and business work flows.
- **System integration**: Plug & play; Connections; Service oriented architectures; Integration platforms+ value added services; Cabling; Gateways; Middleware; Development methods and tools (Integrated design environments (IDE); HW simulation & testing environments; UML profiles; Data modelling methods).
- **Interoperability & standards**, which addresses RTD needs in relation with data models and real time (in-side and out-side building) communication protocols.
- **Knowledge sharing:** Access to knowledge; Knowledge management; Knowledge repositories (Contents; Personalisation / user profiling); Knowledge mining and semantic search; Long-term data archival and recovery.
- **Virtualisation of built environment**: Office optimisation; Server virtualisation technology.

Vision

EEB is managed in a holistic way through the seamless integration of the ICT tools that are used in the different stages of the building life cycle (definition, realization and usage), both off-line and real-time process, in such a way that the building becomes an active component in the energy networks. The integration of ICT tools is also complemented by the integration and cooperation among the multiple stakeholders that take part in the building life cycle, in such a way that better decision making processes achieved by the participation of all relevant actors and taking advantage of experiences in existing buildings. The increasing energy demand in buildings due to the massive adoption of ICT systems will be mitigated by the adoption of strategies for virtualisation of built environment Drivers

Drivers

The market and policy trends that generate the need for new technologies are the following ones:

- Computers already are present in all phases of the building life cycle (design, operation, maintenance,...).
- New generations will be "digital", they are used to manage computers and ICT devices since their childhood.

- Tendency toward smartbuildings and the adoption of BEM systems. "Intelligent ambient" will be a reality in buildings.
- Wireless control networks are permanently increasing their reliability and autonomy and reducing their deployment costs.
- Increasing energy costs and other sectors experiences (automotive, electrical appliances …) are starting to change the perception of users about EE in buildings, increasing their concern about this topic.
- Energy price tends toward real-time energy cost.
- During the next years, legislation will be toughened in all aspects that are related with the climatic change.
- The integration of local generation in buildings (renewable energy sources and micro-CHP) will change the role of buildings in energy networks from energy consumers to energy "*prosumers*". This evolution will require higher integration of buildings in the management of the energy networks, sometimes as energy consumers, other times as energy generator.
- The evolution of the energy networks toward smartgrids will require more detailed information about buildings energy demand in order to optimize energy management at district level.
- Organisations (regulatory bodies, designers, contractors, facilities management, owners, etc.) and increasingly buildings (including communities) through efficient semantic based knowledge management platforms identify, collect, organise, share, adapt, use, and create energy efficient solutions and practices. New good energy efficiency practices are where possible, translated to tangible programmable processes to be automated through ICTs.
- Need for contextualised access to building's information including energy. This is typically scattered at best and rarely stored in a meaningful or accessible form that is retrievable (buildings have a history and lifespan that far exceeds the storage media (paper, old disc formats, etc.) and formats (historic data formats, paper-based information, etc.) that are offered by technology) and usable.

Barriers

The constraints that limit or prevent the development or exploitation of new technologies are the following ones:

- Fragmentation of the value chain in the construction sector. A lot of stakeholders take part in the building life cycle, many of them SMEs or even micro-SMEs. Usually, no one leads the overall process.
- The *project oriented approach* of building sectors makes more complex the adoption of long term strategies.
- Current fixed energy prices don't motivate users to adopt active energy management systems.
- Lack of skilled workforce and data to manage advanced control systems.
- Renovation process in building sector is very slow. Compatibility with existing systems and installations is required.
- For existing buildings, a significant amount of effort is required to first retrieve all relevant information, and to then compile and structure it in meaningful form to be used by new solutions.
- Lack of precision of the current simulation tools, what reduces their credibility and the interest of stakeholders on them.
- Management and maintenance of current BEMS is very complex.

Impacts

Expected benefits and business opportunities to key stakeholders from using the results of the proposed RTD can be summarized in the following ones:

- Dramatic reduction in building project execution times and costs, but increasing the quality of the buildings at the same time: mistakes are avoided at definition stage; decision making is based on more accurate data; knowledge that was generated in previous projects is taken into account.
- Complete access to contextual building knowledge in real-time to allow for informed decision making based on retrieved facts/patterns, future trends, and prognosis.
- Optimization of the energy performance of buildings from their life cycle perspective. This means reduction in the energy costs and CO2 emissions.
- Higher integration of buildings in the energy networks, what makes possible exploiting the energy generation and storage of buildings and their associated equipments, as future electric cars.
- New business opportunities in the context of building managements for facility managers and energy traders.
- The demand for ICT tools for the building sector is increased because their added valued is raised through the interoperabity among them.
- The market for BACS (Building Automation and Control Systems) is increased because energy efficiency complements current market drivers, as comfort or security, and wireless technologies make easier their adoption in existing buildings.
- Telecommunication networks and services are the backbone that support building process and buildings integration in the energy networks.

Scenarios

A. Websites used to gather and disseminate energy-efficiency "good practices"

Users are in a position to type a question and retrieve relevant answers on the energy performance of similar types of buildings as theirs. Through this, they can make informed decisions on how to improve the energy performance of their buildings. Based on their decisions and corresponding actions, the knowledge/experience gained is transferred to relevant websites for incorporation in new/updated good practices. Furthermore, websites are considered to be able to use intelligent semantic search and knowledge mining to extract knowledge from other industrial disciplines (e.g. manufacturing, aerospace, etc.) to propose possible solutions to problems that have not yet been reported/documented in the building industry.

B. Information standards: BIM for energy information modelling data

You are discussing with the architect the design of your new home. You suggest him increasing the size of bedrooms and living room windows and using more energy efficient glasses. He makes the changes through his CAD tool (size, material and unitary costs) and updates the corresponding BIM with the new windows. These changes automatically launch the energy simulation tool, which reads the updated BIM and in few seconds update it with the results of the energy simulation. The updating of the BIM with the energy simulation results automatically launches the cost analysis tool and it provides you in few seconds information about the new building realization cost and energy costs during building life cycle. You make a final decision about the change with a detailed knowledge about its impact in the energy consumption of the building and its cost.

C. Communication standards: network protocols for energy data exchange

The BEMs that you have installed in your building provide you detailed information about the use of energy (lighting, computers, HVAC,…). This information is automatically read and analyzed by your facility management tool and detect that the energy consumption for HVAC is increasing. This data are compared with the data of your neighbourhood that are offered by the ESCO and it is observed they have not been increased in this period. You ask for a review of the system and it is detected that the boiler is not working properly. The boiler is repaired and the energy consumption returns to the expected values.

Related roadmaps/SRAs

Strategic Research Agenda for the European Construction Sector. European Construction Technology Platform (ECTP) [41].

Research Priorities for the Definition of a Multi-Annual Roadmap and Longer Term Strategy. Energy-efficient Buildings (EeB) PPP. [35].

NESSI Strategic Research Agenda. [30].

eMobility Strategic Research Agenda [17].

Networked and Electronic Media (NEM) - Strategic Research Agenda [40].

Table 6. Roadmap for integration technologies

Drivers	- Digitalization of building process and future generations - Social awareness about relevance of energy efficiency and evolution toward real-time energy cost - Integration of local generation in buildings
Barriers	- Fragmentation and "project oriented approach" of building sector and complexity of dealing with existing buildings - Lack of knowledge about building life cycle energy costs and current energy price policies
Impacts	- Better knowledge about building life cycle energy performance - More affordable energy efficient buildings and them integration in the smartgrids concept. - New business opportunities for ICT , energy and building sectors - Higher sustainability with lesser consumption of resources (i.e. travel, energy, etc) via changes to the way we work

State of the Art	Short term	Medium term	Long term	Vision
Process integration: Files are the main integration mechanism and email the communication tool	Information server based workflows	Friendlier the interaction with the information systems	Automation of the workflows definition	EEB is managed in a holistic way through the seamless integration of the definition, realization and usage stages oriented design and operation tools and the collaboration of all the stakeholders in order to achieve the maximum elegy efficiency in the building life cycle and taking advantage of the experience in previous buildings
System integration: A wide variety of different technologies, from different vendors and companies, are coexisting	Definition of the gateway installed in each buildings and SOA based Integration Service Platform (ISP)	Making more efficient and friendly ISP and extending it neighbourhood level	Creating a common European vocabulary and new develop-ment methods and tools	
Interoperability & standards: Many non interoperable and partial standards	Definition of a common BIM for building life cycle energy efficiency	Unified open communication standard for monitoring and basic control operation	Uncertainty management and ntegration with standards from other domains	
Knowledge sharing: Even when knowledge exits, it is not discovered because is scattered in different non-compatible media and formats..	Continuous learning; community forums for discussion; digital catalogues of building products/services containing parametric information.	Easy access to knowledge about energy efficiency in building, which is modelled according to standards and easily accessible; user awareness tools (syndication).	Template solutions based on good practices; ubiquitous and context-based access to inter-organisational knowledge platforms	
Virtualisation:	Definition of elements for "Office of the Future"; Application Virtualisation; human controlled avatar in 3D virtual meetings	Virtual Office Space; Virtualisa-tion incorporating Cloud compu-ting and Software-as-a-Service (SaaS); Head-Up Displays for virtual reality meetings	Virtual Personalised Desk and Energy Harvesting for Office of the Future'; real-time and self-predictive/adaptive virtualisation	

2.5.1 Process integration

State of the art

Current processes integration is mainly based on digital files that are shared by the different stakeholders that take part in the definition, realization and use of the building. In many cases, these files are "*flat files*", without semantic value, as "*doc*" or "*gif*" files, without semantic value, that require their understanding and handling by human experts.

At the same time, workflows are manually managed, been the email the main tool to support the interaction among the stakeholders. Although more advanced tools exists, and in some cases are been successfully used in other industrial sectors, as automotive or aeronautic ones, these tools haven't been adopted by the construction sector because they need to be adapted to its specificities: fragmentation, very dynamic, changing and large supply networks, mobility… This approach makes very complex the collaboration among several actors, because a lot of version of the same document coexists and it is needed an "*editor*" that compiles and manage all contributions.

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

Short term RTD priorities

The main short term RTD priorities should make possible evolving from the current file based workflows to information server based workflows, which integrates multiple collaboration mechanism, as multimedia documents sharing and live editing, comments annotation…, in such a way that interactions among the stakeholders can be automatically traced and managed in a holistic way [6]. The main research topics to achieve this goal are:

<u>Adaptive user interfaces</u> that are able of automatically adapt the user interface of the collaboration environment to the characteristics of the current terminal and to the capabilities, access rights and current context of the user.

<u>System security.</u> Protection against threats and attacks, as Denial of Service and Intrusion detection, privacy of the members of the community, identity management and trust in service based systems.

<u>Model Management tools.</u> Multiple actors take place in the building design, execution and operation of a building, but everyone has a specific role that defines what he is allowed to see and edit. Model management tools need to make possible the interaction among this large and dynamic group of stakeholders during the building life cycle and support multimedia contents. Model management tools need to be based on open standards that warranty their interoperability with other ICT tools (see section 2.5.3 Interoperability and standards).

<u>Integration of synchronous and asynchronous collaboration tools.</u> Although many collaboration tools exist (email, file servers, blogs, social networks, document sharing and life editing …), there is no link among them. All this tools should be integrated in order to share the same configuration data and easily tracing the evolution of the building.

Medium term RTD priorities

Once all building life cycle information is permanently accessible to the stakeholders, the next priority is making friendlier the interaction with the information systems. The main research topics to achieve this goal are:

Natural and multimedia user interface. Natural interfaces mimic typical human-to-human patterns of interaction such as speech, gestures, facial expressions and body motion. Current user interfaces are good for *desktop environments*, but building sector activities are characterized by the mobility, what makes the use of the keyboard, mouse and conventional screens very uncomfortable.

Intelligent and multimedia search engines. The large amount of information in multiple formats (text, plans, virtual reality models, photographs, video,…) which is in permanent evolution requires the development of new search engines that are able of recognize the current context of the user of the system and satisfy his information demand with the most accurate data.

Integration of digital and real worlds. Some technologies, as Distributed Virtual Reality and Augmented Reality, could make possible the integration of the digital information (installations design, simulation results …) with the real world (physic building, stakeholders …). This approach makes more accessible and understandable the building information to the large number of stakeholders that are implied in the decision making process and allows them reaching a common agreement without any limitation due to where they are.

Long term RTD priorities

The main long term priority should be the automation of the workflows definition. The evolution toward the "service model paradigm" should make possible discovering how is responsible of every activity in the process and adapting the workflow to the characteristics of every building (legislation, weather conditions, …). "*The service transformation is shaping around the service user and his/her needs. Soon users will only accept seamless, personalized and fully user-centric services*" [30]. The main research topics to achieve this goal are:

Modelling, construction and management of hybrid service-based systems. The evolution toward service oriented systems will require the integration of internal and/or external data and ICT tools.

Dynamic formalization, management and interaction of business processes implemented through services. This necessitates the transition from business processes to IT applications: modelling of functional and non-functional properties, modelling of mediators to support negotiation; supporting round-trip management of business processes, supported by simulation of end-to-end business processes based on a multi-model approach, …

Support for event-orientation. The complexity of future building will require ICT systems that are able of detecting and facing multiple events.

2.5.2 System integration

State of the art

Regarding current state about automation & control, monitoring, quality of service and wireless sensor networks (= "Intelligent control") within a building or a buildings neighbourhood, a wide variety of different technologies, from different vendors and companies, are coexisting. Moreover and consequently, another limitation is that information exchanged through these technologies is heterogeneous. It doesn't have the same meaning from one system to the other and data are defined regarding each particular technology. Another problem is the lack of a common standardized infrastructure and middleware in order to facilitate System integration.

An envisaged way of progress on the topic of System integration is the definition of a Service Oriented Architecture platform able to communicate with the devices installed in a building (or neighbourhood of buildings). This platform requires the definition of some middleware components behaving like gateways or bridges between it and the multiple installed devices. Finally, and after the global infrastructure has been initialized, the most difficult effort is to define a common vocabulary amongst all the system(s) components, in order to be able to reuse the solution as a generic pattern, in many buildings, ideally working with many kinds of pluggable devices.

Short term RTD priorities

Envisaged short term priorities could be:

- Define the features and specifications of the gateway installed in each buildings: This gateway (or 'smartbox') could use the Open Source frameworks (e.g. OSGI) in order to activate or not (on demand) some services it offers. This box would participate to the middleware infrastructure behaving as a router or bridge between the whole set of devices installed in a building and the common Integration Service Platform outside of the building.
- Define the Integration Service Platform using a Service Oriented Architecture: This common SOA platform would form the core of the System Integration and would behave like data repository storing information coming from/sent to the intelligent controls. Within the scope of the short term priority, a proof of concept would be specified to be used with only one intelligent control gateway in a particular and significant building.

Medium term RTD priorities

Envisioned medium term priorities could be:

- Improve the features and specifications of the gateway (and middleware) installed in each building by adding "plug and play" features:

  Each new component (device, sensor) in a building would be automatically discovered as well as its primitive functions for information access. Moreover, the gateway should be in charge of information translation from component vocabulary (and data format) to platform vocabulary and vice-versa.
- Improve the Integration Service Platform definition:

  Within the scope of this priority, the platform should be able to communicate with several intelligent control gateways located in distinct buildings. Moreover, some services software should be implemented inside the platform to allow holistic provision, operation, monitoring and maintenance of systems.
- Refine the "hard" middleware installed inside buildings:

  Improve cabling inside buildings, by using new emerging wire technologies in order to reduce the number of intermediate cabinets, and preferably use wireless connections between the devices/sensors and the gateway.

Long term RTD priorities

Long-term research is needed to:

- Create a common European vocabulary between the unique integration platform, the multiple intelligent control gateways and the devices & sensors installed in buildings. To achieve this goal, an Ontology could be defined. Ontology is a formal specification of concepts, their relationships and constraint, in an area of interest. It is represented in a formal, machine-readable language. Ontologies are used for communication between people with different viewpoints, interoperability between heterogeneous systems and systems engineering.

- Create some new development methods and tools such as simulation and test environments, Integrated Development Environments (IDE), but also data models and schemas for unified development processes, such as UML based representations. UML models could rely on UML profiles and concepts defined in Ontologies for the domain (business and technical areas).

2.5.3 Interoperability and standards

State of the art

Currently, a lot of ICT tools are used along the building life cycle (design and simulation tools, management tools, control and monitoring systems, energy trading systems,…). However, there is a lack of interoperability among them. Although standards exists, there are too much and fully independent standards. In some cases, several standards are competitors among them, as KNX and Lonworks in relation with building automation. In other cases, the lack coordination among complementary standards makes very complex the interoperability of the building sector ICT tools.

Nowadays, the best way to warranty the interoperability among different ICT tools and systems is the adoption of software suites and control systems that are developed by a unique software developer, which are based on proprietary standards or open standards that are "*lightly*" adapted.

Short term RTD priorities

The main short term RTD priority is the definition of a common BIM for energy efficiency in buildings, bridging the gap between the building design and the building operation tools. As it is described in the REEB vision (deliverable "D4.1 - Vision for ICT supported Energy Efficiency in Construction"), the holistic approach to the EEB requires the integration and management of many data that are generated during building life cycle. Until now, data modelling have been approached from partial initiatives (architectural design, installations design, building operation…). Consequently, managing all this information is very complex: it requires knowing many different standards; there are redundant definitions for the same concept; not all the concepts are accurately modelled…

This extend BIM should be complemented with standardization of the building components catalogues, in such a way that any building component can be automatically searched and integrated in the BIM.

Medium term RTD priorities

Once a common data model for energy efficiency in buildings is available, the next objective should be development of a unified open communication standard for monitoring and basic control operation that allows feeding this data model with real time data and their exploitation.

This monitoring and control protocol should support also the management of dynamic building components (for example, active windows, shading devices …), in such a way that their energy efficiency parameter in the BIM are automatically updated when their energy performances are changed.

Current divergence of standards dissuades users from the adoption of BEMS. At the same time, the adoption of this common standard would provide the necessary data for innovative applications, as predictive maintenance tools, continuous tuning of the building operation parameters, benchmarking of buildings energy performances, user awareness tools, ...

This open standard should be based on already existing standards. This approach would make easier the integration of existing systems and minimize the effort that should be done by the sector to adopt it.

At the same, this standard should take into account not only in-side building data demands, but also out-side building data demands (interaction with utilities, local authorities, facility managers,…). At this point, special attention should be paid to privacy aspects, in such a way that the data aggregation is detailed enough to provide relevant information, but not too much to compromise the privacy of building users.

Long term RTD priorities

The main long term RTD priorities in relation with interoperability and standards are the following ones:

Uncertainty management. The common use of estimation/simulation tools during the building design process will imply that their numerical results need to be complemented with information that defines their uncertainty level, taking into account the input data that have been used.

Integration with standards from other domains. Day by day, more powerful remote control functionality will be added to electrical appliances at home (washing machines, ovens and stoves…), which require the development of new control standards. The development of this standards should be done in such a way that they are compatible with existing energy management one.

2.5.4 Knowledge sharing

State of the art

Some experience and previous solutions are at best available through personal or organisational archives, but new solutions to the same problem are continuously re-invented due to a lack of efficient solutions to retrieve existing knowledge that may be stored in historic media formats and be based on old standards or proprietary data formats. There are limited if at all any mechanisms for the capture, structuring, and propagation of knowledge not only across organisations, but within organisations themselves. At best, some basic file/document management systems exist. Where forerunners are embracing web-based collaboration environments and even using syndication tools the knowledge stored in such solutions is limited and efficient means for its capture, structuring, and most importantly sharing are missing. There is limited support for interactive training, simulation, etc.

Short term RTD priorities

Education, e- & m-learning: Tools that support and enable continuous learning on energy efficiency solutions and practices within buildings. These would cover e.g. training in optimisation of energy usage of building components through efficient ICTs. They could contain basic tutorials, training simulators, or even wizards to guide through execution of a certain task.

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

Catalogues: Intelligent digital catalogues of building products/services. They should contain substantial product/service information (much more than simple geometry) in parametric form. As an example, they could contain guidelines for the construction (how to build or how to use or how to make more energy efficient) of the product. Domain knowledge is available in reusable form from catalogues including e.g. energy efficiency related attributes. Examples: best practices, materials, products and components, suppliers, guidelines.

Medium term RTD priorities

Model-based knowledge management: Impact models explain causal dependencies, mechanisms and potential impacts of ICT on energy efficiency. Parametric knowledge of building energy efficiency related attributes is embedded and managed through building, neighborhood, and eventually city information models.

Semantic knowledge services and toolkits: Meta repositories (that will provide definitions of, and relationships, and mappings between different energy efficiency related information repositories, knowledge sources and ontologies) and semantic knowledge services and toolkits will be able to modify / adjust / enhance user's queries so as to retrieve the required information from the relevant sources (taking into account, the implicit context of the query).

User awareness tools: Syndication tools (e.g. RSS) are used to push new relevant information to "users" of facilities and provide advice on better "user" practices for efficient energy management within buildings.

Standards: Use of or compliance to (where necessary through interfaces or translators) to relevant standards) to support better sharing of energy efficiency related information and interoperability of this information across different relevant applications.

Long term RTD priorities

Ambient access technologies: Ubiquitous, personalised and context-dependent access to energy efficiency knowledge is necessary and can be provided through ambient access technologies. These technologies will be based on an integrated use of ontologies, semantic web, context aware applications, knowledge processes, personal usage patterns, knowledge agents, etc.

Template solutions: Reusable knowledge templates i.e. object with built-in configuration rules and constraints. These enable customisation of proven solutions without re-invention. Configuration rules allow simulation of different design combinations and provide means to optimised energy efficient solutions. Template solutions can be used to where possible translate identified good energy efficiency practices to tangible programmable processes to be automated through ICTs.

Knowledge platforms: Platforms and services dedicated to energy efficiency knowledge sharing in inter-organisational and inter-community environments. They support knowledge sharing based on user profiling, and push of adapted/relevant energy efficiency information to each profile. These should ideally be transparent to the users and be accessible by different applications and search services.

2.5.5 Virtualisation of built environment

State of the art

The benefits of virtualisation, regardless of the methods adopted, is clear: "Do more with less". With the concept of virtualisation and the automation of the advanced features using ICT technologies, we could create a built environment that easily integrates business growth and change with maximum productivity and lower costs.

We have identified the key application areas where ICT has played a significant role in virtualisation of built environment and enabling energy efficiency, including: (1) office optimisation i.e. save office space and energy use ; (2) server virtualisation i.e. need for less hardware saves energy and costs; and (3) electronic conferencing. Much of the technology already exists or is on the horizon, but we can expect the evolution of more sophisticated ICT solutions (or deployments) to grow over time. While each virtualisation method individually improves energy efficiency and productivity, deployments which bring them together and leverage on future energy demands and usage patterns in future workplace deliver the best benefit.

Regarding current state about built environments, there is a lack of integration and virtualisation at different levels. For instance, traditional energy intensive computing processes are still running separately (on different servers), there is no resources optimization and business applications are multiple, each one with a dedicated access point for users. Another example is the "old fashion" usage of office environment where the use of energy and available space are not optimised.

An envisaged way of progress on the topic is the definition of a virtual workspace integrating all business applications and software components which could be accessed from any computer inside or outside the office, or even from construction site. Other ways to explore refer to office use optimization, server virtualisation and cloud computing.

One of the goals of these actions is to save energy / reduce energy consumption, share physical and software resources and consume lesser space inside office environments.

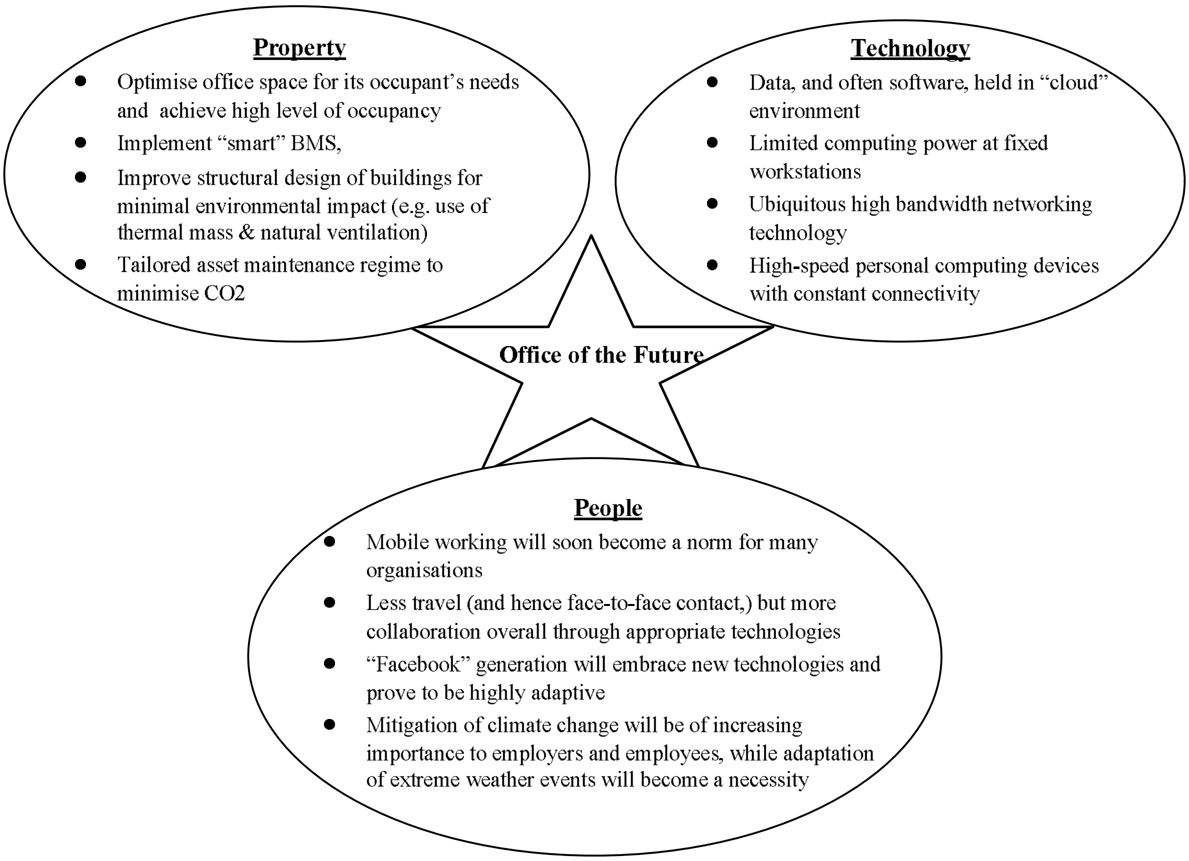

Figure 11. Three Key Elements for Office of the Future [10]

Short term RTD priorities

Office Optimisation. Three key elements (see diagram above) have to be addressed to realise the "Office of the Future". Much of the techniques described in the three key elements are quite familiar to us, but most offices have not taken enough measures to implement these techniques extensively. Also in this case we ought to consider the fundamental changes to the way we work to help inspire the prospect of innovating new ways of working.

Virtualisation. Organisations take advantage of application virtualisation than just server consolidation to improve their operational effectiveness, which focuses more on flexible and effective application management (e.g. better application mobility, availability and reliability; flexible load balancing between applications; better interoperability with I/O devices, etc). This allows ICT to be better aligned with business needs for scalability, continuity and disaster recovery.

Electronic Conferencing. The increasing use of human-controlled avatar in a 3D virtual meeting for people to discuss and interact. This includes features that are not offered in traditional electronic conferencing, such as:

- Real-time interaction using multiple collaboration tools at one time e.g. audio, chat screen, whiteboard, etc
- Existing applications can be displayed and shared e.g. Word, PowerPoint, etc
- Support very large number of meeting users (or groups)

Other envisaged short term priorities could be:

- Initialize a first version of a single global virtual workspace integrating communication and some (or all) projects and business applications.
- Perform a virtualisation / de-materialisation of physical processes through the application of ICT technology. This allows traditional, high impact and energy intensive processes to be replaced by low carbon impact technologies, still enabling users to achieve the same ends.
- Start an office optimization by restructuring companies physical work environment: the use of available space can be optimised, temporarily unused space can be dynamically reallocated, desktops can be replaced with notebooks, etc.

Medium term RTD priorities

Office Optimisation. Greater number of people are beginning to work from different locations, thus an alternative to owning a traditional office is to have (or rent) a flexible virtual office space (i.e. on a demand-basis for meeting rooms, private offices and professional office services) or a combination of physical office space and virtual office solutions. All these save the expensive overheads of maintaining an office space and thus reduces energy, travelling time and carbon emissions. Solutions for a virtual office should be scalable to suit the variable needs from a small office to a large one.

Virtualisation. The demand for more flexibility and mobility could create the transition from application virtualisation to a future path incorporating Cloud computing and Software-as-a-Service (SaaS). Therefore, organisations acquire managed hosted services for a virtualised environment to suit the needs of the business without having to procure unnecessary hardware/software (thus making savings in cost and energy use).

Electronic Conferencing. Technology Advances could stretch the vision of virtual reality meetings to the next level. Head-Up Displays could replace PC screens to offer a genuinely realistic alternative to travel, building on the growing acceptance of meetings in “Second Life” environments. In the event of adverse weather conditions (e.g. snowing, flooding, etc), virtual reality meetings could become the only feasible option over face-to-face interactions.

Other envisaged medium term priorities could be:

- Improve the virtual workspace created in previous term by allowing its use from outside the office (e.g. home). Possibly get inspired by the work done by Google on its Chrome virtual Operating System.
- Continue to enhance dematerialisation of processes by introducing server virtualisation. It is seen as an effective technology for consolidation because the separate operations and

applications of a number of servers can be handled by a single server without losing functionality.

Long term RTD priorities

Office Optimisation and Electronic Conferencing. Future vision of our "Office of the Future" will be "smart" in terms of how the workplace uses energy (i.e. deciding how to best draw out the available resources) and can be self-managed in an optimum fashion to suit the needs of the occupants with very little human intervention. The use of electronic conferencing will be more pervasive, easy-to-use and can be flexibly integrated into most tool/applications of diverse environment.

Some of the predicted developments include:

- Virtual Personalised Desk – Interactive touch interfaces powered with full network capabilities that link every employee to his/her working environment, without a need for a monitor and desktop PC, while personalising the look of their own desk space. Mobile workers can stay connected to the office and world using a virtual personalised desk that are available in public areas e.g. airports, shopping centres, etc.
- Energy Harvesting – Use of ICT to provide capabilities in functions such as wireless connectivity, processing, actuating, etc. for energy harvesting and storage and/or building up self-powered devices in an office environment.

Virtualisation. Virtualisation could make real-time and self-predictive/adaptive decisions to balance workload across servers/ multiple data centres in the same or different geographical locations based on changing workload requirements and adverse conditions.

Other envisaged long term priorities could be:

- Improve the virtual workspace created in previous term by allowing its use on different dedicated interfaces and devices (ubiquitous approach) to allow, for instance, its use on a construction site. Perform a research work on new interactive touch interfaces powered with full network capabilities that would link employees to their working environment without a need for a monitor and desktop regular PC.
- Develop some new business and management concepts such as home-working, tele-working, mobile-working, flexible working hours, e-commerce, etc.
- Work on emerging computing concepts such as Cloud Computing in which services are provided by a "cloud" that is to say a set of distinct remote computers. The client application doesn't care about the particular involved server(s), it just requires and invokes a service which fulfil its requirements.

3 Conclusions

This intermediate report of REEB WP4 builds on the previous report:

- D4.1 Vision for ICT supported Energy Efficiency in Construction,

which in turn is based on the work done by other REEB WPs on:

- WP2 Inventory of best practices,
- WP3 Inventory of RTD results.

The roadmap outlines RTD priorities in short, medium and long term within the domain on ICT enabled energy efficient buildings. These are organised into 5 main categories. The 4 first ones are application domain oriented and the 5th one is cross-cutting:

1. Tools for integrated design and production;
2. Intelligent & Integrated Control;
3. User awareness & decision support;
4. Energy management & trading;
5. Integration technologies.

At this stage the roadmap reflects mainly the conclusions made by the REEB consortium. Therefore it is issued for peer review and dialog between the REEB consortium and key stakeholders who are also asked to suggest targeted RTD actions within the scope of the roadmap. Based on the received feedback the next reports will be:

- D4.3 Suggestions for Implementation Actions for ICT supported Energy Efficiency in Construction.
  This document will summarise the suggested RTD actions. It is expected that some of them will lead to modifications of the roadmap.
- D4.4 Book: Strategic Research Roadmap and Implementation Recommendations for ICT Supported Energy Efficiency in Construction.
  The book will be a consolidation of the 3 first reports on Vision, Roadmap and Implementation suggestions. Feedback from stakeholders to these 3 reports will be considered in order to present a consensus view supported by a wide community.

4 Acknowledgements

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