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

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SEVENTH FRAMEWORK PROGRAMME

D4.1 Vision for ICT supported Energy Efficiency in Construction

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Summary

This document presents visions for ICT supported energy efficiency buildings. At high level the impacts of ICT are envisaged to evolve as follows:

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

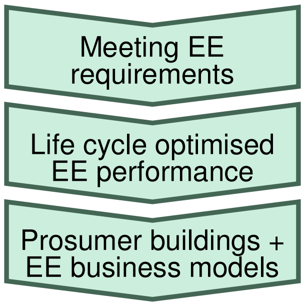

Figure 1. Envisioned evolution of energy efficient buildings

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 adjustments 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 *(Figure 2)*.

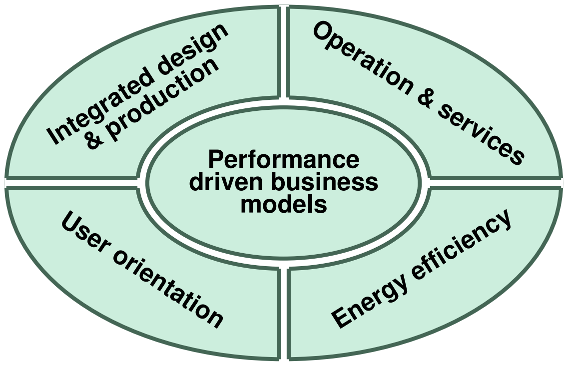

Figure 2. Industrial priorities

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

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

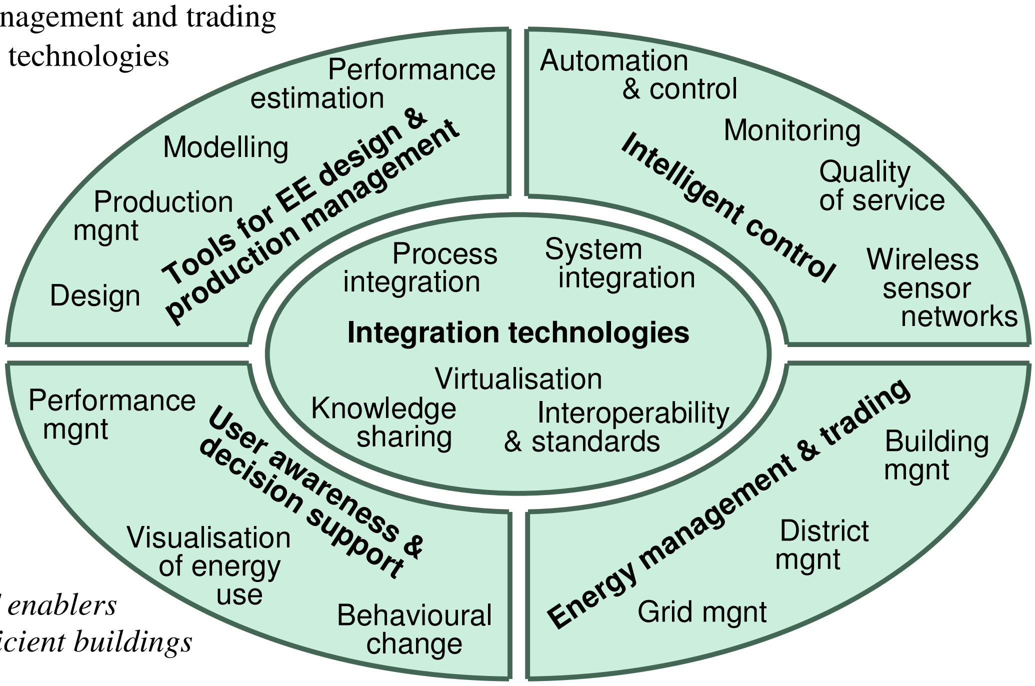

Figure 3. ICT enablers for energy efficient buildings

Table 1. Summary of envisioned ICT support at various life cycle stages of product/service

Life cycle	Applications / systems
Design *Product definition stage*	• Capturing user/client requirements and formalising them into measurable indicators. Verification methods. Design for EE. • Catalogues of materials, components, connections, interfaces. Configuration design tools. Design for constructability and flexibility. • Regulation data bases and automatic code checking tools. • Design for operability and system integration. • Applications for analysis, design, simulation, visualisation etc.
Production *Product realisation stage*	• Translation of performance requirements to all stakeholders and verifying compliance. • Tagging (e.g. RFID) and tracing of materials, products, equipment, vehicles etc. Access control. Quality control. • E-Business. On-line construction site. Ambient production status information. Manufacturing automation. • Off-site manufacturing of components and modules. Industrialised methods on-site production & renovation. • Applications for constructability assessment, scheduling & planning. Recording as-built model.
Operation *Product usage stage*	• Recording as-used model. Facility management applications. Integration of BIM with real time information e.g. simulation based predictive control. • Monitoring of actual performance and verifying compliance to requirements. Feedback to users. • Sensors, actuators, wireless networks. Monitoring the condition and status of materials, components & systems. • Intelligent and integrated automation & control. • Energy management & trading. • Predictive maintenance of installations and Renewable Energy Sources (RES).
Integration *Throughout all life cycle stages*	Collaboration support: • Integrated design environments. • Communication & teamwork support applications. • Logistics & supply network management. • Integrated project management environments. • Platforms for service integration. • Virtualisation of living & working environments. Interoperability standards: • Exchanging and sharing building information models (BIMs). • Technical and commercial information about products & services. • Automation and control protocols, interfaces and gateways. Knowledge sharing: • Catalogues of re-usable knowledge, guidelines, best practices. • Catalogues of template solutions. • Catalogues of products, services, suppliers. • Adaptive and self-learning systems. • Services/forums for benchmarking the performance of buildings.

Contents

Abbreviations

BACS ....Building Automation and Control Systems
B&C ....Building and Construction
BEM ....Building Energy Management system
BIM ....Building Information Model; Building Information Modelling.
CRM ....Customer Relationship Management.
CSCW.........Computer Supported Collaborative Work.
CWE ....Collaborative working environment.
DG ISM ......Directorate General - Information Society & Media, the organisation within the European Commission responsible for ICT research.
DP...............Dynamic Pricing.
E2B EI ....Energy Efficient Buildings European Initiative.
E2BA..........Energy Efficient Buildings Association.
EC...............European Commission.
ECTP ....European Construction Technology Platform. One out of about 42 ETPs.
EDM ....Electronic Document Management.
EE...............Energy Efficient / Efficiency.
EEB ....Energy Efficient Buildings.
EPBD..........Energy Performance of Buildings Directive.
ESCO..........Energy Saving COmpany.
ETP.............European Technology Platform (e.g.ECTP). Industry-lead organisations to define the vision, SRA and IAP in specific sectors and/or technology domains.
EuP ....Directive on Ecodesign requirements for energy-using products.
FA...............Focus Area; a thematic group within an ETP.
GHG ....Green House Gases.
HVAC.........Heating, Ventilating, and Air Conditioning
IAP ....Implementation Action Plan; a key deliverable of all ETPs. Also used by REEB as a short title for its recommendations (deliverable D4.3).
ICT ....Information and Communication Technologies.
ICT4EE.......ICT for Energy Efficiency. This acronym is frequently used by ICTforSG.
ICT4EEB ....ICT for Energy Efficient Buildings. Used in this document.
ICTforSG....European Commission, DG Information Society and Media, Unit H4 "ICT for Sustainable Growth".
IDM ....Information Delivery Manual, a standard for BIM interoperability.
IFC.............Industry Foundation Classes, a standard for BIM interoperability.
JTI...............Joint Technology Initiative, an industry-lead organisation to manage European RTD.
JU ....Joint Undertaking, a legal entity operating a JTI, e.g. Artemis JU.
MVD ....Model View Definition, a standard for BIM interoperability.
OS...............Operating system.
PDM ....Product Data Management.
PPP ....Public Private Partnership.
PV...............Photovoltaic.
REEB..........European strategic research Roadmap to ICT enabled Energy-Efficiency in Buildings and constructions. Full title of this project.
RES.............Renewable Energy Sources
RTD............Research and Technology Development. This acronym is commonly used by the EC. Practically a synonym of “Research and Development, R&D”.
SCADA .... Supervisory Control And Data Acquisition
SCM ....Supply Chain Management.
SOA............Service Oriented Architecture.
SRA ....Strategic Research Agenda; a key deliverable of all ETPs.
WfM ....Workflow Management.

1 Introduction

1.1 Scope and context

This report is the first 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.

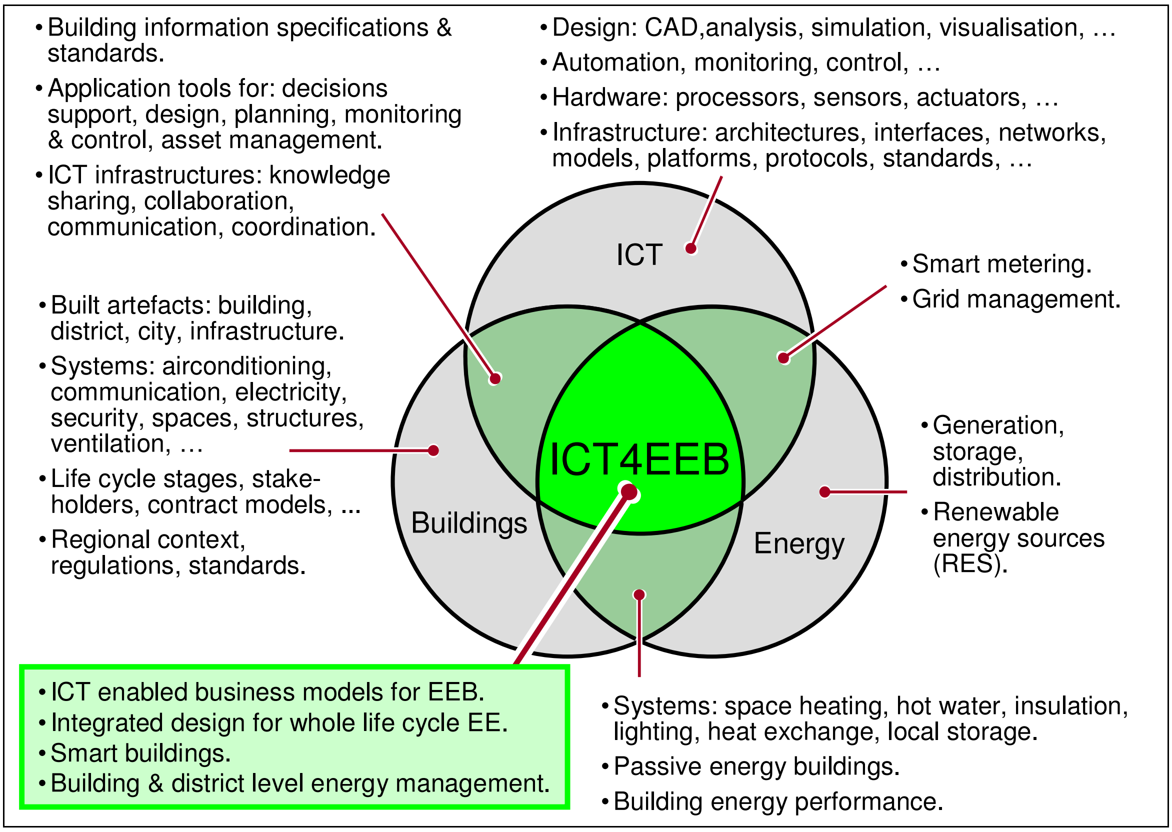

Figure 4. Scope of the ICT4EEB vision: integration of technologies for buildings, ICT and energy

This public deliverable is prepared by REEB Task 4.1: Develop and Validate Vision. The baseline of the work is provided by the EC policies and the visions and strategies of a number of related initiatives (see the Appendix). The purpose, together with the forthcoming other WP4 documents listed below, is to support the definition of RTD topics 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

Forthcoming deliverables of WP4 following this report will be:

- 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.

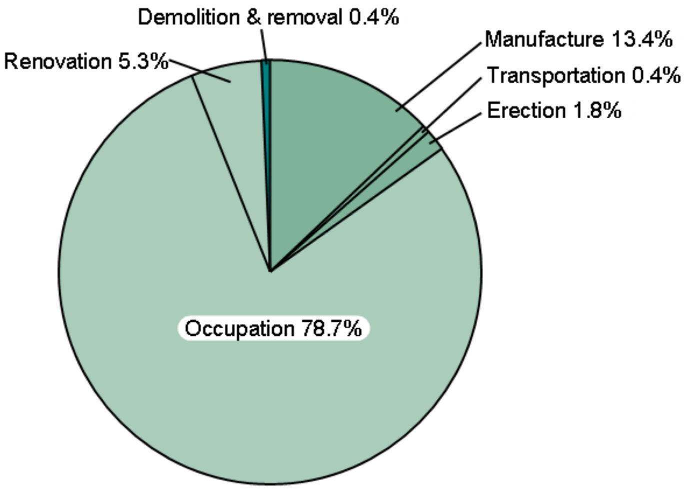

Figure 5. Energy use during life cycle of buildings [8]

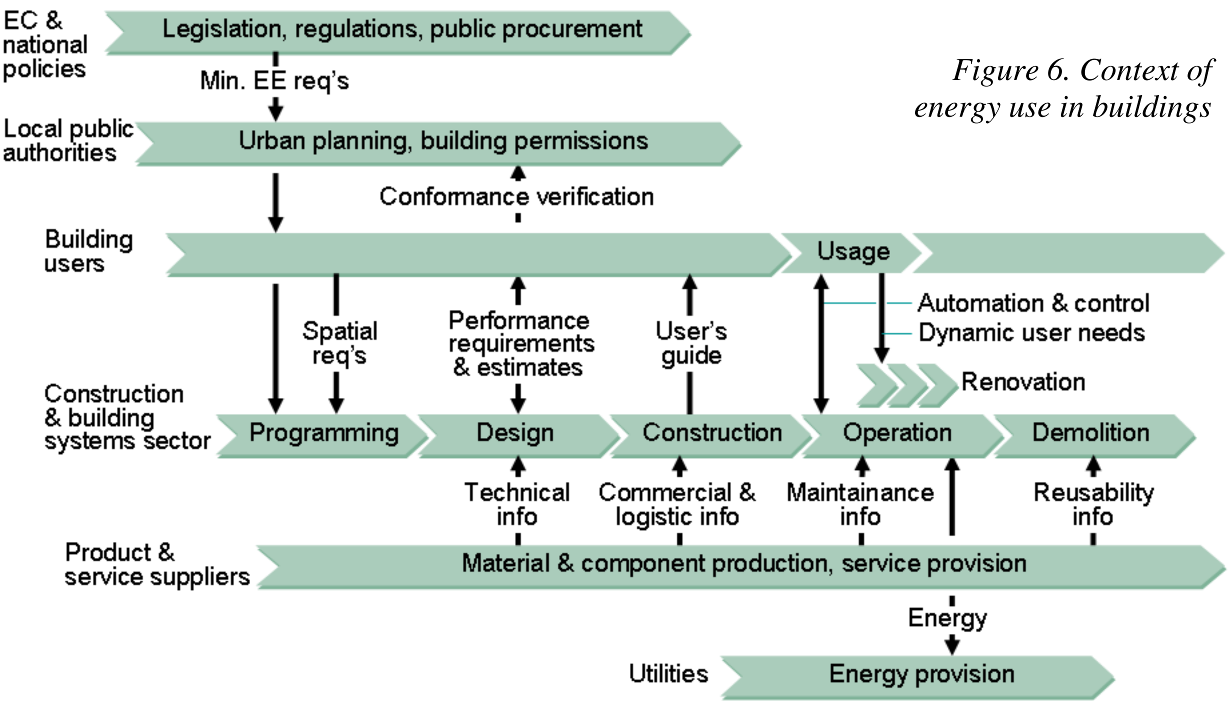

Figure 6. Context of energy use in buildings

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 ICT-enabled business opportunities

ICT is a key enabler for energy efficiency –driven new business models in construction. Synergies and co-operation between construction, energy and ICT companies will enable a new range of business models where innovative local and regional small and medium enterprises will play a key role. New business models will overcome the non-technological barriers that discourage innovation and market deployment. The contractual and financial conditions provide incentives to all stakeholders towards life-cycle optimised buildings.

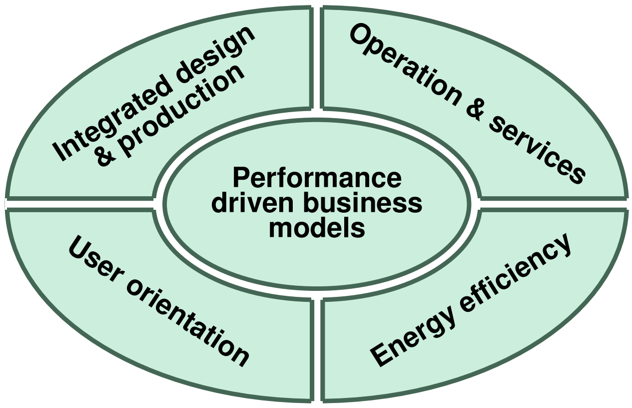

Figure 7. Construction sector priorities - the main drivers for ICT use

- Definition stage: Value proposition supported by verifiable methods to assess, simulate & visualise product performance for decision making.
- Realisation stage: Integration of value & supply chain. New financial & contractual models for value delivery. Handling of IPR of digital information. Validating performance.
- Usage stage: Integrated services for operation, monitoring, maintenance, (energy) management at building, district and grid levels.

Some examples of the new business opportunities [12] that will appear based on ICT-enabled energy efficient buildings are:

- <u>System and service integration:</u> Integrating offerings from different vendors, companies will offer integrated solutions.
- <u>User-customisable energy efficient design:</u> The client is able to select and customise his future building selecting generic components from a given catalog. For each component, it is possible to analyse the energy consumption figures of the whole building not only during the operation phase but also taking into account embodied energy of each material so that he is able to select the most efficient solution.
- Innovative Building-technology <u>products and electrical devices</u>: dealing with more energy efficient space-heating, HVAC equipments, elevators, water boilers, appliances, white goods, etc.
- <u>Transparency-creating products:</u> educating energy end users about the impact of their choices and behaviours on their energy consumption and therefore encouraging more conscious use of energy. These products will include smart meters and graphic user interfaces at the consumer’s location.
- <u>Remote operational services:</u> The telecom provider plays an important role in the delivery of smart building applications to the end-user or to the utility providers. End-users are offered energy-efficiency applications using multimodal interactive interfaces (TV, PC, mobile phone, ...) e.g. smart metering details, real-time power consumption of appliances,

temperature monitoring, etc. The utility company is offered smart metering services. In addition, the telecom provider enables maintenance of the BMS, and other services like remote monitoring, surveillance and management/control of appliances. ICT can empower people to remotely manage their vacation homes, enable technicians to manage many buildings from a central location thereby achieving scale and energy efficiencies (less commuting). The telecom provider is likely to play an important role in providing secure remote access to smart homes and buildings.

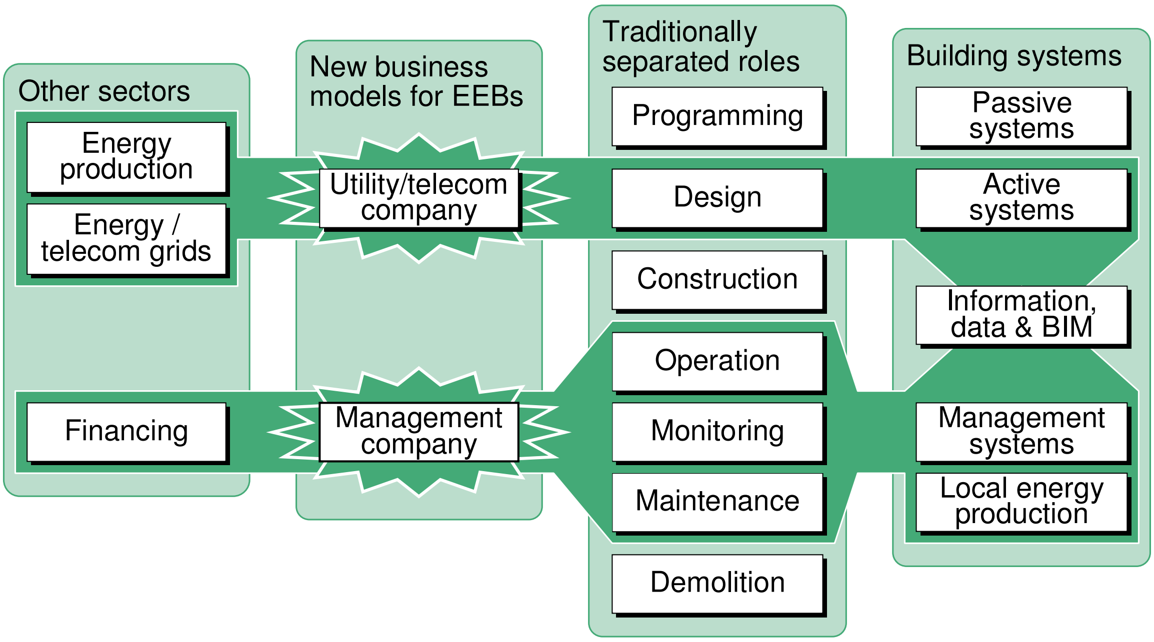

Figure 8. Examples of opportunities to new stakeholders involved in ICT-based Energy Efficient buildings business models

- Energy services: Energy Services Companies (ESCOs) will offer a wide range of activities to energy users, including operation and maintenance of installations, energy supply, often in the form of power and heat from co-generation, facility management (covering technical, cleaning, safety and security) and energy management including energy audits, consulting, demand monitoring and management.
- Holistic maintenance and operation services: Innovative companies provide remote predictive maintenance services of interoperable building-technology products and electrical devices such as energy production and storage, space-heating, HVAC equipments, elevators, water boilers, appliances, white goods as well other services like remote monitoring, surveillance and management/control of appliances. User is able to remotely manage their vacation homes, enable technicians to manage many buildings from a central location thereby achieving scale and energy efficiencies (less commuting).
- Local building energy trading: Within a district, prosumer buildings are trading the excess energy they produce but do not consume at a given time, enabling peak-shaving strategies. During the day, an office building buys energy from a residential house which is mostly empty at that moment. When the working day ends, the residential house is able to buy the spare energy produced by or accumulated by the office building.

1.5 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 [41] with some variations depending on the specific contents. In this vision 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.

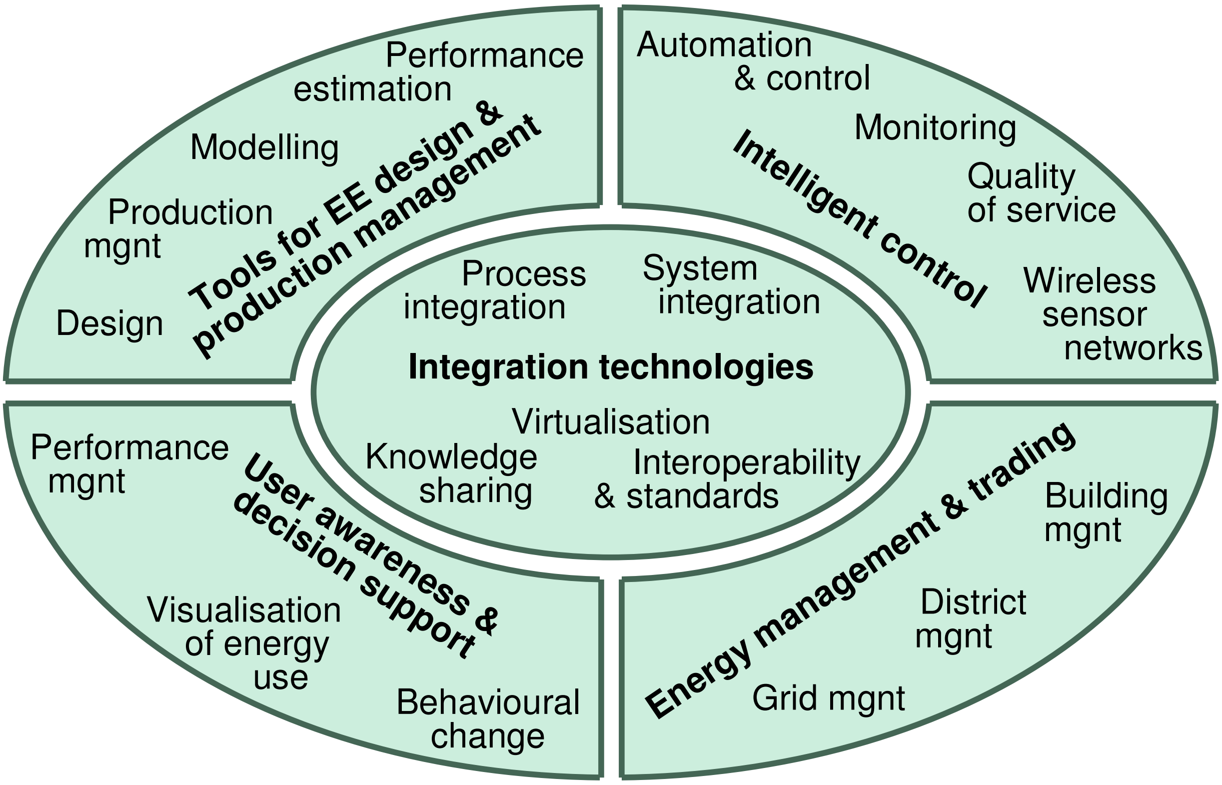

Figure 9. RTD priorities in the "ICT for energy efficient buildings" domain

2 Vision

The vision is derived from the aspirations of the construction sector and related sectors, and several RTD strategies that are summarised in the Appendix.

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

- Short term: ICT will be used to ensure that existing and new buildings meet the current and emerging requirements for energy efficiency.
- Medium term: ICT tools will enable life cycle optimised design and energy management during operation.
- Long term: ICT will enable and support new business models and processes driven by energy efficiency. Building have evolved from energy consumers to “prosumers” (producer + consumer).

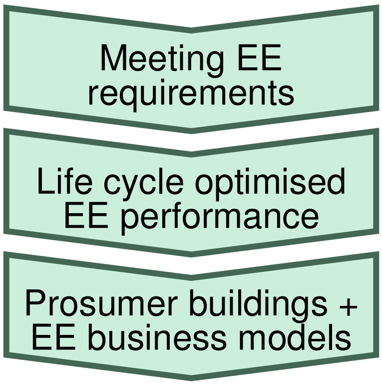

Figure 10. Vision of ICT enabled energy efficiency in short, medium and long term

ICT is often perceived by practitioners as various specific computing and automation applications. However, ICT is also a generic enabler for integration of various processes, applications, systems and technologies: databases, collaboration & communication infrastructures, interoperability standards, knowledge management, modelling, optimisation, simulation, visualisation, etc.

REEB has identified 5 key research areas where ICT enables both new applications and integration:

- Integrated design and production management.
- Intelligent and integrated control.
- User awareness and decision support.
- Energy management & trading.
- Integration technologies.

The role of ICT in these areas is envisaged as follows:

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

In the following the key research areas are mapped to the 3 generic product life cycle stages:

- product definition – programming, conception, design;
- product realisation – planning, production, manufacturing, procurement, assembly;
- product usage – facility management, operation, maintenance.

Definition stage – programming, conception, design

- Requirement management: capturing user/client requirements and formalising them into measurable indicators. Performance assessment and compliance verification methods.
- Catalogues of materials, components, connections, interfaces. Configuration design tools. Design for constructability.
- Applications for analysis, design, optimisation, simulation, visualisation, virtual & augmented reality and decisions support.
- Design methodologies for system integration, energy efficiency and operability.
- Standards for exchanging and sharing building information models (BIMs).
- Integrated design environments. Communication & teamwork support applications and platforms.
- Catalogues of re-usable knowledge, guidelines and best practices. Configuration tools to customise solutions from “templates”.
- Value proposition/branding supported by verifiable methods to assess, simulate & visualise product performance for decision making and contracting.
- Regulation data bases and automatic code compliance checking tools.

Realisation stage – planning, production, manufacturing, procurement, assembly

- Translation of performance requirements to all stakeholders in the supply network and verifying compliance.
- Off-site manufacturing of components and modules. Manufacturing automation. Industrialised methods on-site production & renovation. Applications for constructability assessment, scheduling & planning. Recording as-built model. Tagging (e.g. RFID) and tracing of materials, products, equipment, vehicles etc. Site access control. Quality control. Ambient production status information e.g. via mobile user interfaces. On-line construction site.
- E-business platforms. Standards for technical and commercial information about products & services.
- Logistics & supply network management. Integrated project management environments.
- Catalogues of products, services and suppliers.
- Integration of value & supply chain. New financial & contractual models for value driven delivery. Handling of IPR of digital information.

Usage stage

- Monitoring of actual performance and verifying compliance to requirements. Smart metering. Feedback on energy consumption to users.
- “Industrialised” service provision.
- Recording as-used model. Facility management applications. Integration of BIM with real time information (e.g. simulation based predictive control).
- Embedded intelligence: sensors, actuators, wireless networks. Automation & control. Monitoring of the condition and status of materials, components & systems. Integration of various smart systems (e.g. access control and energy management).
- Standards for automation and control protocols, interfaces and gateways.

- Platforms and gateways for integration of ambient services. Virtualisation of living & working environments.
- Adaptive and self-learning systems. Platforms/forums for benchmarking the performance of buildings.
- Integrated services for operation, monitoring, maintenance, (energy) management at building and district levels.
- Predictive maintenance of installations and Renewable Energy Sources (RES).§

More detailed description of the envisaged ICT for Energy Efficient Buildings is elaborated in Section 3.

3 Trends and scenarios

3.1 Tools for integrated EE design and production management

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

3.1.1 Design

Integrated design is a key to the energy efficiency of buildings: integration of various design tools to support a holistic process bringing together the views of different stakeholders to address the whole life of buildings. Multidisciplinary collaborative design ensuring fully integrated whole life optimised solutions meeting the required performance instead of sub-optimisation. This section describes the main ingredients of integrated design. Integration technologies are addressed in section 3.5.

Examples of typical design tools:

- Architectural, structural and building systems design (CAD), dimensioning, analysis, modelling and simulation.
- Viewing, reviewing, marking-up and annotation.
- Collaborative document and model management systems for information exchange.

CAD

Building design: Versatile design (CAD), analysis and simulation tools are deployed to design and plan buildings that fit within the environments in which they are built. Energy aspects are integrated into various everyday design tools leading to reduced efforts to use advanced special purpose tools. Examples: thermal and lighting modelling, air and fluid dynamic modelling etc.

District design / Urban planning: ICT applications are used, not only to design individual buildings but, to simulate and analyse holistically complex urban systems considering aspects like local climate, transportation, commuting, energy generation, balancing and trading within a district etc.

Collaboration support enables various stakeholders to work together addressing the whole life of the building (section 3.5.1).

Building information modelling (BIM) increases the semantic power of data making it usable for multiple purposes and thus increases the overall effectiveness of ICT applications (section 3.1.3). Standardisation of BIM leads to increasing interoperability between various tools (section 3.5.3).

Performance management tools help with identifying & capturing the client's needs and allow them to see transparently how their requirements are transformed to best in-class solutions (section 3.3.1).

Knowledge sharing: Re-usable information is provided from e-catalogues. Examples: material/product properties such as embedded energy, best practices, reference solutions ("templates") (section 3.5.4).

Configuration management

The emerging "mass-customisation" trend in construction will lead to radical changes of the design process. Detailed design becomes closely related to product and system development while "configuration design" is applied to assemble and customise pre-existing "template" solutions to project specific solutions. Realisation of this trend can already be seen in Japan where house manufacturing is quite advanced and well perceived in the market [60]. New building design tools are needed. Relevant concepts can be adopted from other industry sectors: customer segmentation, configuration management, product life cycle management. Expected benefits to EEBs include e.g. optimised combinations of building and energy solutions, and related services. [21]

Visualisation of design solutions

Visualisation of design solutions for decision support: All stakeholders are provided customised visual information about the energy performance (e.g. to demonstrate to clients the performance of their asset before they decide to construct i.e. 'try before you buy' or to test alternative courses of action i.e. 'what if' analysis).

A virtual building, created by means of modelling (BIM), can be viewed as if it were a real building, and more: analysed simulated etc.

3.1.2 Production management

Examples of typical construction management tools:
- Project scheduling, resource planning, management, analysis & simulation.
- Cost planning, estimation and control.
- Tendering, contract preparation and management.
- Customer and supplier relationship management.

It is considered that today about 10% of all CO2 emissions globally come from the production of building materials. Construction activities account for about 5% of energy used, including construction related transport [62]. Construction and demolition waste account for about 22% of all waste [13]. ICT contributions to energy efficient production are related e.g. to the following.

Contracts & supply network management

E-catalogues of manufacturers and suppliers will contain information of their energy-related performance. Contracts are formulated in a way to provide incentives towards whole life performance of the building. New tools are anticipated for preparation and enactment of performance based contracts.

Procurement

Commonly available e-catalogues will provide information about embedded energy in materials & products and production methods. This information enables optimisation of energy efficiency considering the whole life cycles and supply chains of materials, products and the building.

Logistics

Reducing the weight and volume of manufactured products and modules via design optimisation. Reducing the transportation distance via optimised logistics planning; integrated logistics from multiple suppliers and local procurement.

On- and off-site production management

Manufacturing: Improvements of the production processes of building materials reduce embodied energy in buildings. In particular steel, concrete/cement, bricks and glass require very high temperatures that can only be reached today by the burning of fossil fuels.

On-site production management: Decision support for onsite vs. offsite production addressing e.g. assembly of voluminous modules on site. E-catalogues and e-business platforms to support re-use of building materials and components.

3.1.3 Modelling

Building modelling

Most information that is created and used in construction processes is still presented as documents e.g. drawings. This kind of information can only be interpreted by humans and needs to be manually entered into other ICT tools. The required human effort limits the exploitation of already generated information for new useful purposes.

The practice of computer aided modelling is well-established over decades of evolution in architecture, engineering, production planning and manufacturing. In the context of design modelling enables (semi)automatic generation of drawings, list of quantities and specifications.

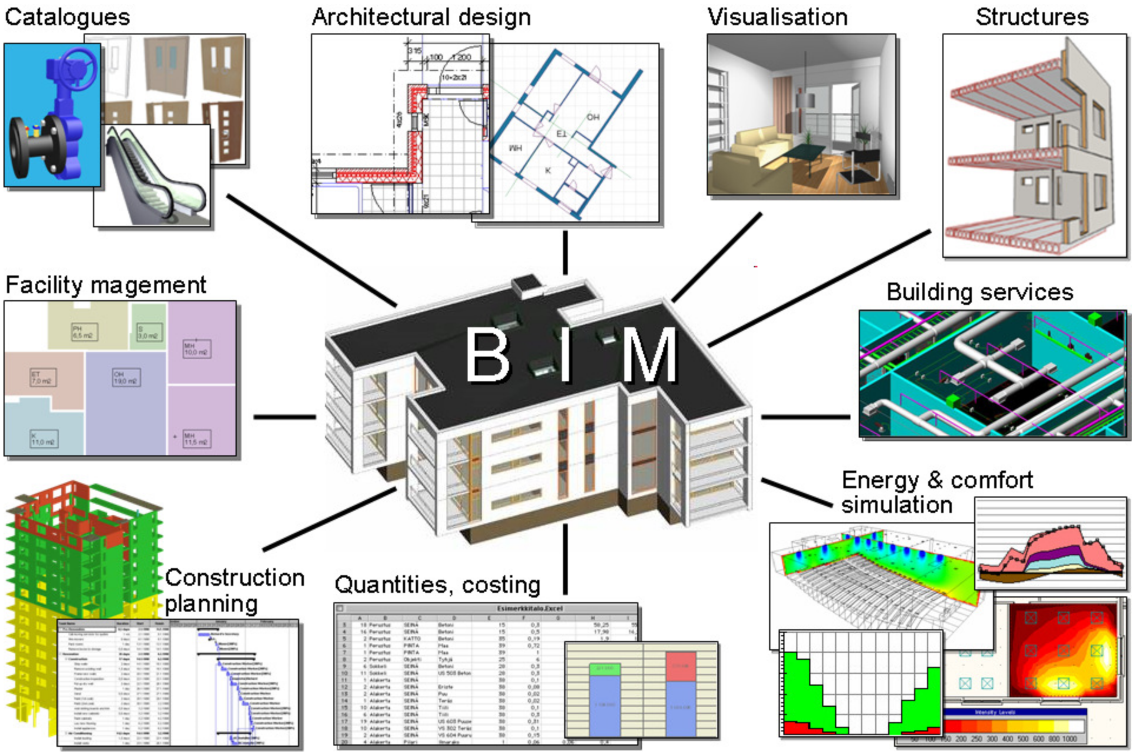

Figure 11. Examples of various engineering applications supported by BIM [36], [66]

The trend is towards model-based information management. A Building Information Model (BIM) is a rich digital representation of the physical and functional characteristics of a facility supporting various ICT-applications that share some common information. BIMs are interpretable computers, which enables automation, systems integration and user/context specific presentations/views. BIM contains multi-disciplinary data specific to a particular building, which is described unambiguously. The result of proper BIM application is an accurate and dynamic multi-dimensional record of the facility's design, construction and operation. Shared building information model may ultimately cover the needs of all involved disciplines providing all the needed views to the information and different computer simulations and analysis. A basic premise of BIM is its use to foster optimal collaboration among project stakeholders throughout the lifecycle of a facility [6], starting from early briefing and ending to the demolition of building and re-use of the materials [66].

Modelling and presentation tools for complex products will be used to create a scalable virtual representation of an entire building that includes all components and systems. Planners and designers can use the information from such “virtual buildings” to obtain resource savings throughout the life cycle of facilities [99].

Urban/district modelling

Similarly as in building design, there is also a trend towards model based urban/district design and planning. The background of this development is from geographical information systems. The resulting standard, CityGML, supports storage and exchange of virtual city models [100]. There is some overlapping with the building information modelling standard IFC, but conversion software tools are available. The vision is that a common information model, or interoperability between different models, covering buildings, urban infrastructures and energy networks will emerge.

Ontologies

An 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 [56]. However, today no such common ontology exists in the ICT4EEB domain limiting the possibilities for holistic approaches across the 3 sub-domains: ICT, energy, buildings.

Semantic mapping

The vision is that integration in the ICT4EEB domain will be achieved via common modeling language and/or semantic mapping.

3.1.4 Performance estimation

Previously, the focus has been on “design-to-specification” and up-front capital costs with no or limited account taken of the longer-term performance [100]. Numerous model-based tools already exist for estimating energy efficiency of buildings: databases, spreadsheets, component and systems analyses, and whole-building energy performance simulation programs [9]. Their use is still hampered by insufficient interoperability (section 3.5.3).

Simulation

Simulation creates useful insights and opportunities for significant energy savings over physical modelling by replacing energy intensive and expensive procedures, and also enables products to be better designed and produced. A large number of simulation tools are available for various applications such as building and district energy consumption, human comfort, lighting, airflow, systems/subsystems, acoustics, fire, traffic etc. These are often based on proprietary models and concepts. The vision is that simulation tool will use available data from other design and analysis tools whereby simulation can be applied at significantly reduced overhead.

Whole-life costing

The primary benefit of whole-life costing is that costs which occur after an asset has been constructed or acquired, such as energy usage, refurbishment, operation and disposal, become an important consideration in decision-making. At district level aspects like commuting, transport, local energy generation, storage and trading will become target for holistic planning and optimisation.

Life cycle assessment

This topic covers a wide suite of applications to analyse the performance of a building through part its whole life from “cradle to grave” with respect to specific criteria such as environmental impact, carbon footprint, energy usage, health, waste, pollution etc. These tools support decision making by all stakeholders, and contractual and regulations-based performance management (section 3.3.1). Commercial tools exist but are not yet commonly used in construction. The vision is also these tools will become easier to use thanks to advances in interoperability and model-based design.

3.2 Intelligent and integrated control

Current and future ambient technologies will make it possible to embed intelligence in potentially any object in the building thanks to affordable chips and micro embedded systems, as well as sensors and actuators, which are then able to dialog thanks to wired and wireless communication techniques. Each material, component, household appliance within a building will further be able to provide useful information, even if the final objective is not necessary to “garnish’ all and every parts and components of a building.

Therefore, the vision proposed for this section “intelligent control” is that 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 contextual information will be interoperable via common protocols and platforms 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 (information systems of) 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.***

Moreover, besides buildings integrating technologies and IT-based systems responding to user’s needs being more comfortable and functional, those buildings will integrate various forms of intuitive interfaces for users’ and building owners’ awareness. In addition to enhanced energy savings, building tenants will see improved comfort and convenience, greater space flexibility, reduced cost, and enhanced safety and security**.**

The ultimate vision consists in positive-energy buildings that will transform buildings from pure consumers to "prosumers" (producers and consumers), including energy production through renewable energies – integrated production and consumption piloted by ICT intelligent systems. They will be integrated into smart energy grids, allowing energy management at the neighborhood, district and city levels.

The vision of the key characteristics and features of the future so-called "Smart Energy-Efficient Buildings" can be summarized as follows – all thanks to appropriate ICT:

- Integration of renewable to Positive-energy buildings;
- Seamless integration into smart energy grids;
- Flexible capacity for interconnection, from all devices in a building to all buildings in a neighborhood;
- Automatically (re-)configurable devices (plug-and-play concept) and equipments;
- Capacity to host sensors and actuators an to integrate them for ICT-controlled energy (and comfort) management;
- Communication between sensors by protocols that are:

  - Safe, in the sense of preventing mixing of information between devices from different buildings/tenants, and preventing data collection by un-allowed third-parties);
  - Low-level energy consuming;
- Wireless and, potentially, endless energy supply for sensors;
- Embedded failure detection and alarms on faulty devices, with methods allowing preventive & predictive maintenance;
- Holistic optimization of the built environment (comfort, security, safety, energy consumption/production/storage) through central control systems or distributed intelligence;
- Integration of complete management systems (central control, sensors and actuators) with:
  - Energy consumption that shall not be more than the energy savings it achieves;
  - Easy-to-use functions, i.e. not based on systems that are more complex than the current set-top-boxes or internet boxes.
- The four main concepts that will be at the basis of "Intelligent control" are the following:
  - Automation and control;
  - Monitoring;
  - Quality of service;
  - Wireless sensors networks.

These concepts are developed in the next sections.

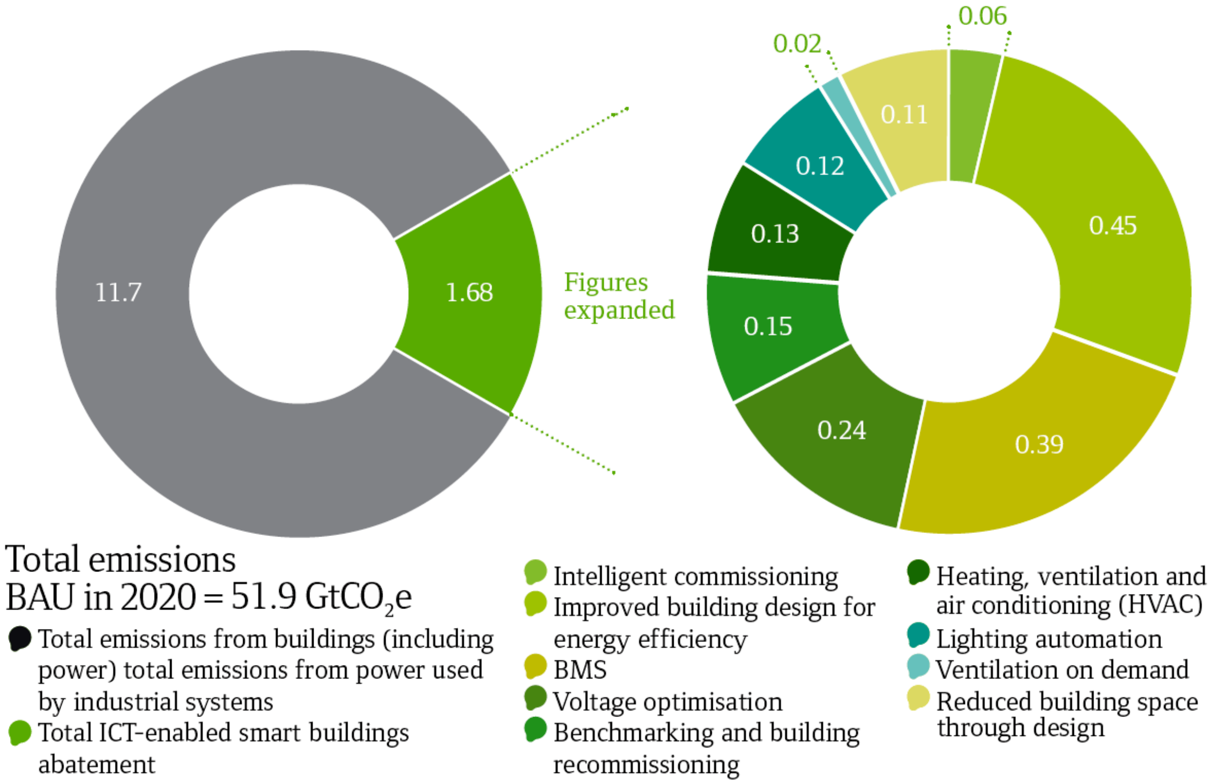

Figure 12. Estimated potential energy savings reachable thanks to ICT in smart buildings (Smart 2020 report [72])

3.2.1 Automation and control

Automation and control consist in methodologies, procedures, equipments and ICT systems that are able to manage (through actuators, micro-chips, 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 (the Internet, energy providers – ESCOs, neighborhood and district energy systems, weather conditions, etc.) in order to ensure a high level of comfort, while optimizing the energy consumption of the whole building.

System concepts

Automation and control systems in a building will be modular (with easy integration of elements in the ICT-based network implemented in the buildings), easily customizable with configuration tools, adaptive and able to learn from their environment. For individual homes or small residential buildings, these systems will be cheap enough so that the return on investment of building automation is unquestionable, compared to the energy savings and energy bills reduction they achieve. ICT-empowered buildings will react to their environments and to users' needs and behaviors proactively. Concrete strategies will be available for each type and/or use of buildings (office buildings, collective/individual residential buildings, public buildings, etc…), that will be easily adaptable (and self-adaptive whenever possible) when parameters related to the buildings, its environment or its occupancy are evolving. Following a systemic approach, global optimisation methods and algorithms (based on genetic algorithms, neural networks or fuzzy logic for instance) according to various contexts (users' profiles, security level, climatic zones, time of year) will help tuning the control system for improved energy efficiency. A very high level of robustness of the mentioned methods and algorithms will be needed in order to actually achieve the targeted energy efficiency results, since any drift (or a wrong configuration) can lead to huge consequences on the final energy balance sheet.

Future automation and control systems' architectures will be scalable, flexible and modular (allowing to add and remove with minimum manual configuration whole applications dedicated to specific services like security, access control, fire supervision, energy management, lighting control, etc.), thanks to open standards for "building operation system" and distributed intelligence.

This level of service will result from the combination of (among other systems): intelligent HVAC, smart lighting, predictive control, management of µ-generation and storage systems.

Intelligent HVAC

HVAC systems (Heating, Ventilating, and Air Conditioning) are equipments used to control and operate Heating, Ventilation and Air-Conditioning devices in a building, such as heaters, air conditioners, boilers, and heat exchangers.

Future intelligent HVAC systems will take into account all information available from the different sensors (temperature, occupancy, light …), weather forecast information and typical user behaviour to optimize HVAC processes, output and consumption. Building behaviour and user profiles will have to be defined through the development of adequate models.

Such systems must moreover be easily programmable to let the "last word" to the user, and self-learning to adapt to change of users and evolution of users' behaviours.

Smart lighting

Smart lighting comprises new light sources (like LED, OLED, compact fluorescent technologies) along with ICT-enhanced lighting control (through occupancy sensors, daylight and ambient light sensors, dimming systems) and will help to further reduce the energy bill of residential and tertiary buildings on a very large scale.

ICT for micro-generation & storage systems

ICT will enable innovative and replicable architectures allowing integration and management of all kinds of renewable energies, to optimize the local distributed production and storage of energy/electricity, and to dynamically pilot the energy requested in various parts of a "building space" and according to some various contexts (user profiling, security level, etc.). The controlling of these systems will be seamlessly integrated to "Building/House Management Systems".

Predictive control

Predictive control consists in both predictive operation of the energy devices in a building, based on weather forecasts, time schedules, user profiles and presence, building energy consumption models; and predictive maintenance based on devices failure detection or drift identification in the global energy consumption.

Predictive control and maintenance offers a huge saving potential (cost of building operation) for industrial and professional buildings. Filters of HVAC devices for example will not be changed for all devices once a year but after a given time in use. This is the same for electrical bulbs. Improved maintenance processes through the use of central automation and control has the potential to deeply improve energy efficiency, productivity and security.

These data must be collected thanks to the sensor network in a central maintenance / control system that is aware of the state of all devices.

3.2.2 Monitoring

Instrumentation

The instrumentation of building elements with sensors, actuators, micro-chips, micro- and nano-embedded systems will allow to collect, filter and produce more and more information locally. This huge amount of distributed information will have to be further consolidated and managed globally through the global monitoring system, in liaison with the Building Management System. Consolidation will be done taking account well identified patterns for energy management improvement.

Monitoring based on smart metering supports performance data analysis, and visualization of energy usage (section 3.3.2).

Smart metering

A smart meter is a meter that can record and report energy consumption information automatically. Smart meters can relay information on a daily, hourly or real-time basis to all involved stakeholders (users, asset managers, energy providers, energy managers, grid managers), allowing any of them to precisely analyze energy consumption, take appropriate measures and/or propose adapted services. The data may be sent to the utility provider either over the wires or wirelessly.

Future smart meters will need to ensure data privacy and security when communicating detailed consumption profiles and data over the concerned communication networks. New privacy policies and rules will have to be agreed upon between the users and the energy providers / grid managers, in order to guarantee that personal data will not be mixed and or sold to third-parties.

3.2.3 Quality of service

Future building control systems will have auto-diagnostics features, and be able to detect failures from any device that is connected to the system. In addition, since voice, data, security and energy information networks will be interconnected, the chosen communication protocols and infrastructure will ensure the highest level of integrity (in terms of data exchange) between all applications.

Quality of services is based on improved diagnostics and secure communications.

Improved diagnostics

Building control systems will feature diagnosis tools that will detect malfunctions in all connected devices (including sensors, communication network, actuators, control software, etc.) and external intrusions in system.

This includes in particular information processing (estimation of bias, reliability of sensors), tools for detecting abnormal consumption, diagnosis for maintenance (new solutions needed for automated or continuous commissioning including diagnosing malfunctioning sensors, actuators, valves…).

Secure communications

Communication protocols will guarantee high transmission reliability and security level as well as data consistency, even for poor transmission rates and for both, wired or wireless transmissions. This aspect is especially important since voice and data transfer means and the building automation system transfer means will converge and use the same structure.

3.2.4 Wireless sensor networks

Future Building Management Systems will be mostly based on networks of wireless sensors and actuators enabling all energy (consumption, production and storage) systems and indoor/outdoor conditions measurement devices to communicate and share energy related information.

Although the performances of wired networks are more than enough in terms of bandwidth and reactivity, wireless networks will be necessary for existing buildings where redeployment of cables is impossible. Moreover, wireless networks feature greater flexibility and allow easy addition or removal of devices with a minimum of efforts. For this, sensors, actuators and energy devices will need to have auto-configuration and reconfiguration capabilities.

Regarding energy supply, all sensors should be automatically supplied or self-supplied, otherwise, once the batteries are empty, the users might not care about replacing the batteries, and the whole system will become useless.

Furthermore, the position of sensors will be determined during the design phase of the building (either for new buildings or for renovation projects), using CAD modeling applications able to optimize the placement of sensors for better performances, robustness and reliability of the measurements.

Hardware

Sensors will be used for detection or measurement of: light, temperature, pressure, noise, humidity, air quality (in terms of CO_2 but also in terms of volatile organic compounds or other polluting agents), presence, activity, etc. They will be highly reliable, with minimum maintenance needs, and remote diagnosis will be possible. Packaged sensors will be able to integrate several functions and thus reduce the total number of necessary sensors.

Ideally, sensors in wireless networks will be completely autonomous in terms of energy supply. They will thus rely on energy harvesting technologies and get their energy through highly sophisticated devices using a suitable mix of technologies like: vibration, temperature gradients, electromagnetic waves, and light via PV (photovoltaic) cells.

To be able to benefit completely of these intermittent energy sources, autonomous wireless sensors will also need high performing rechargeable batteries.

Besides, energy efficient wireless communication protocols that reduce the frequency and amount of information that must be transmitted (e.g. with energy aware routing) will contribute to reduce energy consumption by sensors and allow the possibility of autonomous supply.

Once sensors are autonomous, they can be integrated in windows, walls, doors…, from the beginning of the building construction.

Operating systems

Like explained before, energy consumption of sensors must remain extremely low, but sensors have different radio components, processors, and storage. It is a challenge to integrate them on a WSN platform since their hardware is different and processing raw data can be a problem with limited resources [101]. System software such as the Operating System (OS) must therefore be designed to support these sensor platforms. The OS must provide an especially low consuming API. This API might be used to put the sensor hardware into a stand-by mode in a major period of time and allowing it to wake-up only when some threshold has been reached on its inputs.

The OS must however provide reliable data dissemination protocol for program binaries such as its own sensor firmware. This provides a way to reprogram the sensor fleet in a network and enables, for example, easier bug-fixing or location adaptation when the use of a room or a building is changing drastically.

Wireless sensors can form mesh networks, connecting hundred to thousand devices together. Each sensor is in the same time a leaf as well as a node of the network. Underlying OS must thus be able to handle data transmission and sensor activity in the same time and therefore assure a trade-off while scheduling between data forwarding and its own activity.

Moreover, OS must be able to handle priorities of each task, so that, when battery level is low, only high priority tasks are performed.

Finally, embedded multi-tasking OS will evolve to provide more real-time functionalities to meet different real-time application requirements. Future platforms will 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 will include time synchronization, message routing with data aggregation, and localization [38] and standard abstractions (such as UNIX) and support common programming language (like C) [11].

Network design

Future wireless sensor networks will be designed taking the best of different network topologies (meshed, tree, star, etc.) enabling potentially to dynamically switch between different network topologies, for example dependant on the battery level of the nodes (that can be the sensors themselves). Specific tools will be available for modelling, simulating and testing sensor networks.

Besides, to allow plug-and-play of new sensors and self-configuration of WSN, a set of standardized roles and services, like APIs in the web service model, will be defined and shared.

3.3 User awareness & decision support

3.3.1 Performance management

The vision is that 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.

Understanding ICT impacts

The mechanisms and potential impacts of ICT on energy efficiency are well understood and supported by causal models and evidence. This enables informed decisions to use ICT solutions for improved energy efficiency.

Performance specification

Capturing and formalising user/client requirements, and transforming/conveying them to all stakeholders throughout the process without loosing the original intent. linked to Energy Efficiency performance metrics assessment including decision support & service configuration.

Performance metrics

Components, spaces and buildings are characterised with performance indicators which can be assessed using standardised methods and compliant software tools.

Performance analysis and evaluation

Energy performance assessment and benchmarking tools to measure and tag energy performance labels to buildings. These can lead to improved energy performance, support best value procurement of building products and solutions, and serve as basis for continuous energy performance of buildings, etc.

Prediction, through calculations, simulations or measurements at various stages of the building life cycle. Comparison/benchmarking with similar buildings. The trends towards performance based regulations and contracts raises the need for ICT-based validation tools. As an example, simulation can be applied to validate impacts that can not be directly measured from the physical building.

There is a need to develop and to apply commonly accepted models enabling to characterize the energy consumption of a specific building for several “usual” use patterns. By such models deriving theoretical performance, an estimation of energy consumption will be possible (and the results widely accepted). Of course, these kinds of models have to be continuously updated by real results.

In a first time, the performance of a building will only be measured by “physical” parameters (temperature, light level …) for a given energy consumption. In a second time, social use studies might be able to define a “wellness” parameter that is a mix of temperature, light level, air quality, etc. Based on such works, performance of a given building will then be defined by the ability to optimize “wellness” while minimizing energy consumption. Eventually, there is high potential too from models allowing to confirm (or infirm) energy efficiency with respect to already known parameters from similar buildings.

Recording performance information

Recording performance aspects in the integrated building information models (BIMs), so that performance building assessment and benchmarking could be included in the different stages of BIM in order to support target setting, design for sustainable building, sustainable maintenance and decision making when making procurements and investments. This should be accompanied by the development of guidelines in order to support the further development of existing BIM software. As a very initial sketch, this must rely on:

Conformance validation & commissioning

Building commissioning is a systematic process of ensuring that a building performs and can be operated as intended. Today it is not automatically included as part of the typical design and construction process and is even less applied for continuous performance optimisation throughout the life of the building. Commissioning energy-efficient buildings is especially important because equipment is less likely to be oversized and can not compensate malfunctions. [95]

ICT support tools for commissioning cover e.g. guidance, manual or automated data collection, analysis, simulation, monitoring, optimisation, reporting etc. The vision is that continuous commissioning is part of the whole life time of buildings, supported by embedded functionalities of various ICT tools and systems for e.g. design, building management etc.

Audits and labeling

Standardised audit methodology applied by specialised service companies to analyse existing or planned buildings, and awarding labels based on the observed performance.

3.3.2 Visualisation of energy usage

Energy awareness tools

Through smart metering, visualization of energy usage and performance data analysis, all stakeholders (users and owners, asset managers, energy providers, energy managers) are able to visualize and analyze energy consumption in real-time, take appropriate measures and/or propose adapted services.

A building's energy consumption can be visualized in real-time with the help of energy performance analysis applications, like in current cars where the driver can access real-time fuel consumption and various security information through the dashboard computer. These applications are able to provide the users and stakeholders with adapted and value-added real-time data and/or reports that can help to improve user awareness about energy consumption in the building, and allow the user to act consequently and take decision.

Intuitive feedback to users on real time energy consumption in order to change behaviour on energy-intensive systems usage could reduce 5-15% of energy consumption [22]. Such feedback might include comparison to "better" consumption patterns and might suggest appropriate measures for energy saving. For this, human-centric graphic interfaces will be needed, ensuring the acceptance of embedded systems and other ICT-based solutions for a wide range of users. Such human-centric graphic interfaces will ensure the right level of number and complexity of feedback data (to avoid the users getting information they do not require in the first place). Thus, information provided by these systems will be unobtrusive, and attuned to the user's available attention, taking into account both his/her activity and the urgency of the notified information. Future visualization devices have to integrate all kinds of energy consumption of course, especially those used for heating.

The vision for the type of information that could be displayed on the device is mainly dependent on the evolution of future ICT technologies, integration platforms that are available, and what/how information could be reliably captured and be used.

However, future display technologies could move us away from display screen such as LCD. Examples of potential developments might include: (1) development of very thin, flexible, paper-like display materials that can be added cheaply or even printed onto everyday surfaces, across whole walls and rooms and incorporated into furniture, will offer new surfaces for display projection; (2) use of real world objects as display surfaces, and incorporating display into our environment. [50]. The pace of change lies in the nature of displaying information which can only increase in the future. Its implications though on user behaviour and awareness would be the key in driving the type of changes in future displays.

Examples of energy awareness displays

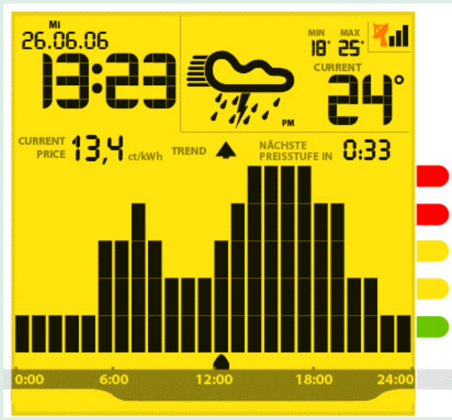

Figure 13. "Electricity Traffic Light" display

The wall mountable tariff display device changes its background to green-yellow-red depending on the electricity price. The device also displays other information like date, time, weather trend and temperature. [28], [29]

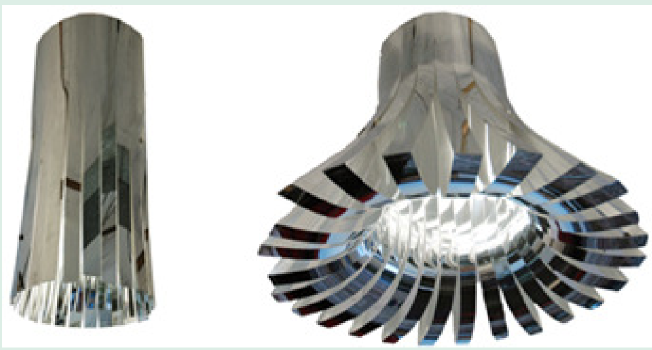

Figure 14. Flower lamp

The lamp reflects energy used by changing its shape. In order to make the lamp more beautiful, a change in behaviour is needed. [1]

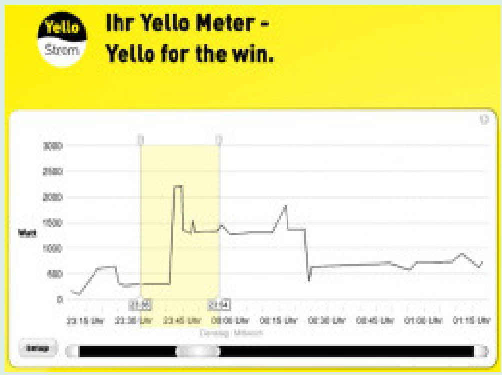

Figure15. "Sparzähler"

Graphical interface that displays data coming from smart meters

3.3.3 Behavioural change by real-time pricing

Opportunities for utilities to offer real-time, dynamic pricing systems that can be tailored to industry and residential needs are becoming more important with the growing significance of smart grid. The assumption is that smart metering is the most effective way to send pricing signals to consumers/building owners and manipulation of such tangible information (i.e. pricing) will potentially transform their power consumption patterns and influence the future design of smart meters.

Future evolution of smart meters appears to be driven by systems that react quickly and intelligently to changing environmental conditions. Hence, they are built with event-driven architectures, rather than request-or time-driven design styles [69].

Therefore we envisage in future that many of the "smart" devices (e.g. HVAC, electrical appliances, etc) are networked in a building/office/room, which can "communicate" with the smart meter based on how much electrical power is being used (or how much money is being spent). This in turn enables self-correction in the operation of the "smart" devices based on pricing decisions made by the consumers/building owners. Similarly it is also possible for utilities, with the consent of building/home owner, to have the ability to change "smart" device settings to increase/reduce demand.

3.4 Energy management & trading

3.4.1 Building as a prosumer

In order to enable the building as a key node within the grid, where it will participate not as a load but as an active element, not only consuming but also producing, a new approach on micro-generation and storage, energy management systems and user interfaces is needed.

The building will become smarter, more energy efficient and enable the customer to become a participant in the energy market.

The following topics represent the needed steps to be taken in order to achieve this vision.

Building energy management systems

Energy Management Systems (EMS) will be self-configuring, choosing the optimal configuration and operating mode depending on the devices / equipments installed, pre-defined strategies, and anticipated needs. This means that all needed information will have to be available in sharable data repositories, including description of all building energy properties (at level of envelope, equipments, devices and deployed ICTs), building usage, assembly and operating rules, etc.

Moreover, such information will have to be described in a standardised way to allow interoperability with simulation and engineering tools. Enhanced BIM will play a major role in that context by storing such unified information, together with open data schemas facilitating the use of BIM data (e.g. gbxml), as well as e-catalogues to describe product properties.

In addition, EMS will have capabilities for being remotely monitored and controlled by the utility or other party. Then, the customer equipment will receive requests for actuating over specific equipments (switch on/off, delays, standby,etc.) based on the needs formulated by the electricity grid. The customer equipment will adjust operations as requested and provide an acknowledgement of receipt and processing through the EMS back to the party or the utility.

Spaces can detect user presence and personalize the environment to the user's preferences: lighting, temperature, indoor air quality etc.

Energy profiles: The information generated about the energy usage of a building will be used for district energy management, optimising energy storage use and/or exchange/trading between buildings etc. [48]

Data repositories – enhanced BIM

It is envisioned that Energy Management Systems will be self-configuring, choosing the optimal configuration and operating mode depending on the devices / equipments installed, pre-defined strategies, and anticipated needs. This means that all needed information will have to be available in sharable data repositories, including description of all building energy properties (at level of envelope, equipments, devices and deployed ICTs), building usage, component installation, assembly and operating rules, maintenance activities history, etc.

Moreover, such information will have to be described in a standardised way to be independent from any specific application software.

BIM (Building Information Model) will play a major role in that context by storing such unified IFC-compliant information during the whole building life cycle, from design to operation, together with open data schemas facilitating the use of BIM data (e.g. gbxml). Besides, component or product properties will be available in suppliers' e-catalogues in a standard format for integration in configuration applications.

Advanced metering infrastructure

In addition to basic meter reading, Advanced Metering Infrastructure (AMI) systems will provide two-way communications that can be used by many functions and, as authorized, by third parties to exchange information with customer devices and systems. Therefore, different application cases appear:

- Support of customer awareness of their instantaneous kWhr electricity pricing
- Support the utilities in the achievement of its load reduction needs. The AMI will help facilitate load reduction at the customer's site by communicating instantaneous kWhr pricing and voluntary load reduction program events to the customer and to various enabling devices at the customer's site.
- Enable customers to more easily participate in utility and non-utility demand reduction programs, by allowing third parties to help them monitor and control their equipment, appliances, etc.

On-demand Energy Management System Optimization

Energy storage, distributed generation, renewables, and demand response will be used as mechanisms to optimize building loads in response to both dynamic pricing (DP) signals and system operational needs. The DP system will provide the DP schedule into the EMS and perform the necessary optimization activities to implement the DP goals.

For example, a large industrial customer that could curtail large loads during peak hours would get a different rate than a small commercial customer with less ability to modify its load. The Grid operator would send price / reliability signals to the customers it serves, using the AMI system and receive information from the customer

The customer's Building Automation System (BAS) will optimize its loads and distributed energy resources (DER), based on the pricing and reliability signals it receives, the load requirements and constraints, and any DER requirements, capabilities, and constraints. The BAS will understand the nature and opportunity for altering consumption based on economic and comfort drivers, and, the physical dynamics of the specific customer premises. The BAS then issues (or updates existing) schedules and other control mechanisms for loads and for DER generation. These control actions may be automatically implemented or may be reviewed and changed by the customer.

Load and Distributed Energy Resources forecast algorithms

The EMS will use site-optimized algorithms to forecast its load and DER generation. It will also determine what additional ancillary services it could offer, such as increased DER generation or emergency load reduction, and calculate what bid prices to offer these ancillary services at.

Smart Appliances

The electricity grid will allow customers to become actively involved in changing their energy consumption habits by connecting their personal Smart Appliances to the utility grid.

The customer will be able to manage their energy usage and costs. Communication will be through the Energy management system/Gateway or the metering system, based on open standards.

3.4.2 Smart Grids

In order to enable a proper energy trading between buildings and between buildings and the grid, a so-called smart grid is needed. A smart grid [77] is defined as the one which uses sensing, embedded processing and digital communications to enable the electricity grid to be:

- observable (able to be measured and visualized)
- controllable (able to manipulated and optimized)
- automated (able to adapt and self-heal)
- fully integrated (fully interoperable with existing systems and with the capacity to incorporate a diverse set of energy sources).

Therefore, it will provide greater transparency and availability of energy market information. It will enable more efficient, automated management of market parameters, such as changes of capacity, and enable a plethora of new products and services. New sources of supply and enhanced control of demand will expand markets and bring together buyers and sellers and remove inefficiencies. It will shift the utility from a commodity provider to a service provider and it will enable consumers to be part of the energy market at local or even regional level.

The vision of smart grid for ICT4EEB includes:

- optimisation of all future investment on buildings;
- creation of cost-savings opportunities;
- reduction of environmental impact with respect to building owner choices; and
- better management of energy supply, integrating both distributed generation and renewable energy sources.

We envisage smart grid has an effect on the liberalisation of electricity markets in the future, which allows building owners/end users to make automated and smart choices about their electricity consumptions based on their individual preference with respect to cost, reliability and environmental impact. Future smart grid should include enhancement across the entire energy supply chain, ensuring the integration of real-time analytic information across the grid, which should result in measurable value for all stakeholders involved.

Different research areas have been identified in order to achieve a real smart grid.

Demand response capabilities

Demand Response is a temporary change in electricity consumption by loads or aggregation of loads in response to market or reliability conditions.

By managing loads through Demand Response and supplies from non-traditional small-scale generation, the opportunity exists to:

- Allow consumer market participation and consumption/billing choices;
- Introduce new markets for aggregators, micro-grid operators, distributed generation, vendors, and consumers;
- Control peak power conditions and limit or remove brownout/blackout instances;
- Flatten consumption curves and shift consumption times;
- Respond to temporary grid anomalies;
- Maximize use of available power and increase system efficiencies through time-of-use (TOU) and dynamic pricing models.

By extending the smart grid within the home (via a home area network), consumer appliances and devices can be controlled remotely, allowing for demand response. In the event of a peak in demand, a central system operator would potentially be able to control both the amount of power generation feeding into the system and the amount of demand drawing from the system. Rather than building an expensive and inefficient "peaking plant" to feed the spikes in demand, the system operator would be able to issue and demand response orders that would trigger a temporary interruption or cycling of noncritical consumption (air conditioners, pool pumps, refrigerators, etc.).

Dynamic Demand is an emerging technology that could reduce the amount of electricity used by appliances, e.g. refrigerators, during peak periods through the automatic configuration of power consumption in response to second-to-second changes in the balance between supply and demand on the grid. This new technology could reduce UK's CO2 emission by 2 million tonnes a year. Refer to two Dynamic Demand case studies [7], [57].

Traditionally, the focus of the use of the Dynamic Demand technology is on services in relation to domestic and industrial refrigeration. The vision is that this technology could also be applied on other industrial equipments commonly used in buildings such as HVAC. It is perceived that the aggregation of many of these loads could provide a cost-effective means to manage the 'supply-and-demand' of the grid. This in effect ensures the quality of energy supply to the grid, which could potentially allow for more integration of renewable electricity generation that are variable in nature.

Indeed, as soon as dynamic electricity prices exist, the price level will determine if it is advisable to e.g.: produce energy and sell it, produce energy and consume it, buy energy and charge the storage systems, sell energy and empty the storage systems. A Demand Response Service Provider will collect energy and ancillary services bids and offers from Dynamic Pricing subscribing customers. The Service Provider will combine those bids into an aggregate bid into the market operations bid/offer system. When accepted, the Service Provider will notify the end customer of the status and requests scheduling of the services.

Real time self-assessments

Through integrated automation, the grid will self-heal, restoring grid components or entire sections of the network if they become damaged. It will detect, analyse and respond to subnormal grid conditions. It will remain resilient, minimizing the consequences and speeding up the time to service restoration. It will enable condition-and performance-based maintenance. Through embedded sensing, automation and control including monitoring and sensors (voltage, current, etc.), automated switches and controls and microprocessing capability, the electricity network will respond to real time conditions.

Load balancing techniques

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; energy management systems will track the balance of supply and demand on the network and control consumer devices to optimize 24-hour energy consumption.

Energy network design and integration

The grid will exhibit "plug and play" scalable and interoperable capabilities. A smart grid will permit a higher transmission and distribution system penetration of renewable generation (e.g. wind and photovoltaic solar energy resources), distributed generation and energy storage (e.g. micro-generation). Asset data collection, analytics and advanced visualization techniques integrated into the utility enterprise systems will provide the tools to optimize network planning.

Secure, ubiquitous and low-latency communications

Resilient, two-way digital communication infrastructure exhibiting appropriate bandwidth and latency and enabling communications from generation source to consumer end point. Low latency communications to support active load balancing and self-correct for interruptions and power quality issues in real time.

3.5 Integration technologies

According with the increasing complexity of the buildings and needed of increasing their energy performances, day by day there will be higher demand of ICT tools that make possible sharing the knowledge that is generated during the buildings life cycle. At the same time, the dependencies and interactions among the different building components is increasing. This means that standards for modelling the interaction and dependencies among the different building components are required. But also process integration tools has to be developed to pave the way toward tighter collaboration among the multiple stakeholders that interact through the building life cycle.

3.5.1 Process integration

Collaboration support

EEB implies the collaboration among a large group of stakeholders during the life cycle of the building.

- At the **definition stage**, there is a strong dependency among the building architectural design, customer preferences, energy demand installations design (HVAC, lighting,…) and RES program. These means that it is needed an agile collaboration and cooperation platform in such a way that all stakeholders always work with updated and accurate date and is able of taking advantage of the information that is provided by others.
- At the **realization stage**, the increasing complexity of the building process and installations will require ICT tools to make possible following the process and assuring the requested quality and building energy performances. At the same time, updating building project documents with "*as-built*" information it is critical for arriving at the building usage stage with the adequate information for the energy efficient operation and maintenance of the building.
- **Usage stage** is the most critical stage from the EEB. EEB at this stage depends on the design decisions that were made at the definition stage, the quality of their implementation (realization stage) and the correct operation and maintenance of the building during it use. At this stage is very important to have updated and accurate information about the building, its installations and its operation conditions, in such a way building users and facility managers can efficiently cooperate to achieve the high energy efficiency of the building during its operation.

Current available ICT groupwork support tools include a multitude of applications and standards for: computer supported collaborative work (CSCW), customer relationship management (CRM), data exchange standards, electronic document management (EDM), product data management (PDM), email, teleconferencing, workflow management (WfM), supply chain management (SCM) etc.

Current technology and licensing conditions are based on the assumption that the same platform is used by all collaborating participants. While this is feasible for internal use by a company and their (static) supply network, it is not applicable in the construction sector where persons are involved in several inter-enterprise projects at any point of time, all with different participants. Various web-based collaboration systems are used in different projects on an ad-hoc basis. This leads to problems regarding license fees, learning and loss of control of internal enterprise workflows.

The **vision** is that distributed team members will be able to collaborate across through ubiquitous and multiplatform ICT tools organizational, geographical and time boundaries as if they were co-located.

There are different ICT technologies and concepts whose development will support the achievement of this vision:

Groupware tools

- Collaborative working environments (CWE) will blur the border between work, leisure and social activities and relations [59].
- Self-configurable systems: Future collaborative working environments will be able to learn and adapt to various working and collaboration styles and to different legal and regulatory conditions (semi-) automatically [59].
- Dynamic virtual teams: Collaboration support services are commercially available to temporary, distributed, cross-organisational project teams.
- Inter-enterprise interoperability: Future CWEs will allow the employees of each organisation to use their familiar in-house systems that are synchronised with the collaboration environments of project partners in a transparent and secure way.
- E-Legal: Web based contract negotiation, enactment and conflict resolution will be legally valid without replication with traditional document/paper based procedures. At the same time, digital signature and digital certificates will guarantee the authoring and authenticity of any digital document.
- Model based workflows: Tools will support model based change & version management and inter-enterprise workflows. Sharing of models will be governed by contractual conditions for ICT based collaboration.
- Model servers will support near real time sharing of model based information (BIMs) between project participants.
- Monitoring and control via Internet: Data that are managed by the control system has to be opened through Internet to other applications, even externals to the building, in such a way that these applications can work with better information. For example, a management of a building could be done from a general "dispatching", which could manage several buildings: in the same area (i.e., smart-grid approach); owned by the company (i.e., hotels, bank offices, public buildings); managed by the same facility manager, etc.

Migration strategies

Migration strategies: The construction sector has been trying to move directly from collaborative document management systems to model management. It is expected that transitional technologies like PDM ("product data management") will be adopted for change & version control and management of BOMs (bills of materials; often called "bills of quantities" in construction). Increasing industrialisation of construction emphasise the use of BOMs as contractually valid information between companies. Eventually PDM- and BIM-based technologies will merge.

Electronic conferencing

Today the common options for electronic conferencing includes tele/web/video-conferencing, which provides an alternative to physical presence and has enormous scope for reducing travel. This affects personal transport energy use significantly, but also energy use in commercial and residential buildings[1].

Another option is the emerging technology of using human-controlled avatar in a 3D virtual meeting for people to discuss and interact. The strength of 3D virtual meeting is its richness, which include features that are not offered in traditional conferencing modes, as follows:

- interaction with people in real-time using multiple collaboration tools at one time that ranged from audio, chat screen, whiteboard to facial images and motions)
- existing applications e.g. Word, PowerPoint, etc, can be displayed and shared.
- support very large numbers of meeting users (or groups).

Potentially, this could represent the next generation of how real-time meetings would be conducted in the future. Over the next 5 or more years, we envisage more uptakes in enterprises to use 3D virtual meetings to replace face-to-face meetings, workshops and conferences.

Future evolution of the tools could lead to the use of virtual personalised desk (see section 3.5.5.1a) in public areas e.g. airports, shopping centres, etc, creating the ability for mobile workers to stay connected to the office and world without using a laptop.

Distributed systems

Distributed systems: Current ICT tools for design and management of energy efficient buildings are developed as "monolithic" systems that include all the software that is required to support their functionality. This approach makes this tools very efficient to developed a fully predefined functionality, but also very rigid and inflexible to evolve and adapt to the changing requirements and users needs.

The **vision** is that ICT tools for EEB will be developed as a dynamic integration platform that is able of discovering in the web the most accurate modules to perform the functionality that is requested by the user, taking into account also the specificities on every building project (local regulations, local building practices…).

There are different ICT technologies and concepts whose development will support the achievement of this vision:

- Service Oriented Applications (SOA). A service-oriented architecture is essentially a collection of services which communicate with each other. The communication can involve either simple data passing or it could involve two or more services coordinating some activity. [70]
- Distributed Data Base applications. A distributed database is a set of databases stored on multiple computers that typically appears to applications as a single database. Consequently, an application can simultaneously access and modify the data in several databases in a network. [25]
- Lightweight Directory Access Protocol (LDAP). LDAP lets you "locate organizations, individuals, and other resources such as files and devices in a network, whether on the Internet or on a corporate intranet," and whether or not you know the domain name, IP address, or geographic whereabouts. [51]

[1] Residential users are generally assumed to be more conscious of energy consumption at home than in the office, thus they would consume lesser energy and be more proactive in creating energy saving initiatives

Business workflows

The evolution toward a more integrated value chain in the building sector and the emerging new business models for EEB will require changing and automating business workflows. This evolution process has been already initiated in the commercial relations among customers and suppliers. In this area, standards, as ebXML[2], and different orchestration tools, as Microsoft BizTalk and Windows Workflow Foundation or SAP Business Workflow, are been used since some years ago. However, more "technical" or domain dependant workflows, are the building design process, are still manually managed, even in the case of using digital files.

The **vision** is seamless integration and automation of the building life cycle business workflows, including management and technical processes.

The main ICT that will support this vision have already referenced in this documents, mainly in relation with collaboration support tools (see "Collaboration support" and "Distributed systems" above, and Standardisation of BIMs in section 3.5.3).

3.5.2 System integration

Plug and play

Each new component in a building is automatically discovered as well as its primitive functions for information access. And by analogy, the principle would be the same at the neighbourhood level, where each new building or each new energy generation unit would be detected and seamlessly integrated in the district energy network. It will lead to highly flexible and scalable networks, where new components can be easily included, existing ones removed, or defective ones detected and isolated from the network (that will possibly show reduced functionalities, but will still work). In addition, this will go with a self-(re)configuration of the system without need of manually reconfiguring the network.

Connections

Many different communication systems and protocols will continue to exist in the future (dedicated bus cables, radio communication, powerline communication/PLC…). The challenge is to make them coexist and interoperate in a seamless way by developing open and technology-agnostic integration platforms. Interoperable connections and protocols will allow holistic provision, operation, monitoring and maintenance of systems. Various control and service software will run on a common integration platform, a "building operation system". Various building services (heating, cooling, lighting, air-conditioning, security etc.), which are currently often operated independently, will be managed holistically.

Service oriented architectures

Integration of BIM, real time information and support services: Service oriented architectures (SOA) integrate BIM-based applications, real time systems and external services (e.g. security, remote operation, maintenance, energy saving etc.). Buildings become integral parts of enterprise information systems.

Integration & service platforms

Common platform ("building operation system" [16]), rather than separate hardware, hosts the control software of various subsystems. At the same time, common real time operating

[2] ebXML (Electronic Business using eXtensible Markup Language), is a modular suite of specifications, supported by the United Nations, that enables enterprises of any size and in any geographical location to conduct business over the Internet. [27]

systems and programming languages that can be used to program and manage components that are developed by any manufacturer.

Value added services: Open information platforms and gateways support external value-added services by specialised companies using information from different subsystems to improve energy-efficiency. Some of the foreseen services are auto-adjustments of buildings according to human behaviours, improved human-to-machine interfaces including pervasive energy awareness displays, self-diagnostics and reporting for remote facility management.

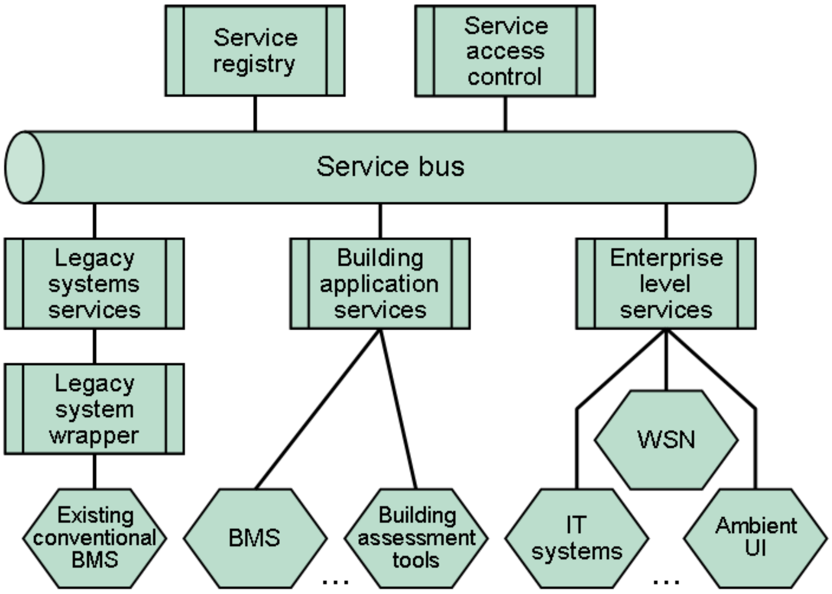

Figure 16. SOA-based building services architecture reference model [52]

Cabling

We need to be aware that the letters ICT may hide a large variety of issues. We have to be careful over the risk of only considering as ICT to "Data", in such way that more passive topics, such as cabling, are forgotten. New emerging wire technologies will allow designers to largely reduce the number of intermediate cabinets. This will imply less environmental impact at the construction stage (less copper, less waste, etc) and regarding Energy Efficiency, less power consumed by the devices (less devices) and less air conditioning to cool those devices.

We need to bear in mind that in the future, in some buildings the energy demand of the ICT systems will be around ¼ of the total energy demand of the building.

Consequently, there is a general awareness in the ICT sector about the need of increasing the sustainability of its products, which is reflected in the GreenIT concept. Although IT systems are usually complementary equipment to the building, their requested infrastructure is very related with the building. Cabling the basic infrastructure of the IT systems and has to be taken into since the building definition stage.

The **vision** is the convergence of the telecommunications and building automation systems networks [71] and that massive high speed data communications are supported by lighter and smaller diameter cables that enable efficient use of pathway spaces for improved airflow through racks and cabinets to maximize pathways and cooling efficiencies. [93]

Gateways

Gateways are H&S systems that allow communication and integration of several building sub-systems (with their associated services) in order to share the resources and functionalities of their different devices. A primary functionality of those gateways is to connect the building to external life cycle support services provided via the Internet or other WAN (e.g. remote management or maintenance), and to share this connection between the different devices and sub-systems. A core part of a home gateway is its middleware (see below). Common examples of gateways are home boxes.

Apart from providing a single usage node, future gateways will fully realize the convergence of several technologies (standard or proprietary ones) through a single device enabling a large range of services that will take advantage of the sharing of common resources to implement holistic strategies (including energy-focused strategies) in smart buildings. They will have multiple user-friendly interfaces (for their configuration, use, maintenance…) adapted to the user type, including various communication channels, and will be largely self-configuring depending on the types of installed devices and chosen services. Besides, they will open the building system to external applications for e.g. remote control, configuration, facility management applications of multiple buildings, security & comfort, etc.

Middleware

To support new context-aware applications that will implement innovative building energy management scenarios, new middleware will be required. Those middleware will facilitate the dynamic integration of heterogeneous networked devices and related application services within the system, and exchange of context data among them, by providing appropriate high-level features for all building system users, including service providers. Such middleware infrastructures will allow powerful services to be easily deployed and permit users to interact with them in a personalized but easy manner. Examples of key services provided by such middleware will include *service discovery* (independent of any specific service discovery protocol), and *service interoperability*. Those middleware will incorporate requirements coming from the involved three worlds (ICT, EE and Construction). They will be preferably built on Open Source frameworks (e.g. OSGI).

Development methods and tools

New applications and services for energy efficiency will require new hardware and software with higher computational power to run not only measurement/control tasks with huge and increasing volume of data & information, but more complex routines such as predictive algorithms, hot reconfiguration, and handling of large history databases.

To enable a wide and open growth of these solutions, a set of development methods and tools will be needed by the developers' community: this includes simulation and test environments, Integrated Development Environments (IDE), but also data models and schemas for unified development processes, such as XML schemas or UML based representations (e.g. UML MARTE for embedded systems).

3.5.3 Interoperability & standards

Interoperability is especially important for the construction sector due to its fragmentation into many disciplines, project-orientation, temporary business relationships and long product life cycles: many stakeholders are involved, each with many different ICT tools and systems for a variety of applications which all share some common information. Interoperability is the key enabler for process and systems integration in the construction sector. It is likely to remain the main ICT-related challenge for construction within the foreseeable future.

There is still a mismatch between the users' need for interoperability and the ICT providers' incentives to support it. Evolution and convergence of ICT standards enable increasingly effective collaborative processes and optimal operation of buildings throughout their life cycle. The main trend is integration of design/planning information, real time information and ultimately the integration of these two streams.

Standardisation of Building Information Model (BIM)

The term BIM refers to digital representation of model based building information. As defined by the the BuildingSmart alliance [10], BIM integrates mainly the static information for design, planning and facility management. Within specific ICT tools, BIM is usually implemented in a proprietary way. Various application tools of different stakeholders are compliant with commonly agreed information definitions. For interoperability between different systems, both the meaning (semantics) and the format (syntax) need to be "understood" by the involved systems. The potential of standard-based BIM is to share information.

Sharing information can be technically achieved via proprietary, non-standardised models and translations. However, due to the large number of stakeholders and the temporary duration of business relationships in construction, the full potential of information sharing can only be achieved via standard-based BIM.

BIMs have to be understood as a holistic strategy to increase the efficiency and sustainability of buildings. The main general advantages of BIMs adoption in building is to enable automated processing of data, thereby reducing need for manual re-entry and interpretation. This leads benefits like: cost savings, reduced errors and time saving due to effective inter-enterprise communication and enhanced re-use of pre-existing knowledge.

An additional impact, especially relevant from the EEB perspective, is that BIMs make affordable to any building project the analysis of its energy performances through multiple CAD/CAE tools (simulation tools, code checking tools, etc.). This allow creating more energy efficient building from the very beginning of the process and knowing in advance the consequences of any programming and design decision.

The **vision** is that all the information that is managed during the building life cycle is supported by an open BIM standard, in such a way that data are not duplicated and always are properly updated and accessible to different stakeholders that have to used them, including building users, and automatically managed by the software tools that they use.

There are different ICT technologies and concepts whose development will support the achievement of this vision:

- Open standards will support interoperability of common software tools without re-entry and loss of meaning (semantics). In parallel, there is also room for non-standard and de-facto industry standard conversion methods for the same aims.
- Ambiguities are avoided by compliance certification and validation of software tools and interfaces.
- File managers: Data exchange between applications, e.g. via file transfer, supports sharing of versioned information (long transactions). This technology is already sufficiently mature to be applied between different legal entities under prevailing contract conditions.
- Model servers: A higher level of interoperability, and deeper collaboration between participants, is achieved by model servers enabling near real time information sharing. This technology is still in an early stage of development and is associated with challenges regarding model evolution management, business models, collaborative working procedures, contract conditions, liabilities, IPR etc.
- Digital catalogues: Manufacturers publish value adding product information including e.g. design rules, constraints and dynamic product behaviour (e.g. thermal). Also other types of re-usable knowledge are available as templates to be configured for customised solutions. Information is delivered from a single source representation in customisable ways to users with various needs and tools. The IPR of embedded knowledge in digital objects is protected. The technology enables open markets and new opportunities for knowledge based businesses.

- Ontologies: Standardised vocabularies/dictionaries, translated to different human languages, will extend interoperability of BIMs to non-model-based information.

Simulation and interoperability

Simulation tools are often based on specific concepts and models. The scope of existing BIM tools and protocols is still insufficient to support simulations. The **vision** is that the data required for simulations will be available and interoperable from other tools e.g. design, modelling and automation & control. [5], [68] , in such a way that building energy efficiency simulation is a seamless process from the definition stage to the usage stage.

Although in some way, interoperability between simulation and estimation tools could be considered as a particular case of “general interoperability”: instead of interoperability among different domain tools (architectural design, HVAC, lighting), this would be interoperability among same domain tools, we pay special attention to this point because in this case the typical interchange of data among applications requires an additional management of the “uncertainty”.

All the ICT technologies that have been described in the previous section (**Erreur ! Source du renvoi introuvable.**) are also strongly related with this topic. Nevertheless, this topic involves a new one:

Uncertainty management. The adoption of estimation/simulation tools during the building design process (and not only at the end of the process) implies that these tools need to manage the uncertainty that it is inherent to the design process. For example, it is need to simulate energy performance of the building before the detailed definition of the envelope. Consequently, the information that is provided by the BIM has to be complemented with other knowledge sources, as typical building solutions in this area, main preferences of the contractor, etc.

Protocols for real time operation data

Building automation, control and management systems are supported by ambient embedded intelligence in components and spaces (see section 0). Most systems in buildings are currently self contained and not able easily to communicate with one another. In smart buildings interoperability of systems, infrastructures and applications allows them to share resources being “aware” about other systems and able to use services from each other.

The vision is a BEM (Building Energy Management System) with seamless “*in-door*” and “*out-door*” integration, in such a way that full interoperability from the level of different manufacturer’s devices to the holistic automation and control of various subsystems and utilities (gas, electricity) SCADAs (Supervisory Control And Data Acquisition).

The interoperability among sensors, actuators, control units and users interfaces from different manufacturers will allow to building designers and facility managers to select the most adequate components, without any dependency on specific manufacturers, and taken advantage of the synergies among different BACS (Building Automation and Control Systems), i.e. security system. Consequently, BEMs will be more affordable (the same infrastructure is shared to multiple applications) and their operation and maintenance during all building life could be guaranteed.

There are different ICT technologies and concepts whose development will support the achievement of this vision:

- Interoperability will be preserved of embedded systems also in changed conditions during the building life cycle.
- Open protocol makes real time data and information from buildings available to various operation & control applications, both for internal management of the building and its

integration in smartgrids. These open protocols should extend from low level protocols to standardized data models, in such a way that not only syntactic (formats) compatibility is achieved, but also semantic interoperability.

- Low energy consumption protocols minimize data interchange in order to extend the batteries life.

Wired protocols

All these protocols are characterized by the need of a physical layer, the wire to transmit the information. However, two main groups of protocols can be identified: those that are require dedicated lines and those that take advantage of power lines (PLC protocols).

In relation with the first group of protocols (dedicated line), the main reference is Ethernet (based on IEEE 802.3), that support the LANs (Local Area Network) which are common in all office buildings and in some homes. LANs are based on TCP/IP protocol. This point makes these networks especially relevant from the real time and control applications point of view, because the main control protocols, as KNX and Lonworks, already support IP implementations.

In relation PLC (Power Line Communications) protocols, the main references are HomePlug and X10, which use the power line as physical layer. X10 was defined in year 1975 and it was the first protocol for building automation systems.

Nowadays it is been observed a tendency toward IP based systems, which are compatible with LAN and WIFI networks, and it is expected that PLC protocols remain as “niche” solutions for very specific uses, as historic buildings.

Wireless protocols

The main characteristic of wireless protocols is that data transmission is done through radio frequency signals, and consequently they make easily accessible any point in the building.

Two main families of protocols can be identified: WPAN protocols and WLAN protocols.

WPAN (Wireless Personal Area Network) protocols are low distance communication oriented protocols, been Bluetooth and ZigBee the main references. Bluetooth is a general purpose protocol and ZigBee is a fully wireless control oriented protocol, which pay especial attention to aspects as low energy consumption.

WLAN (Wireless Local Area Network) protocols are the evolution of the wired LAN to wireless infrastructures. The main protocol is the WIFI protocol (IEEE 802.11), the wireless Ethernet protocol. The main advantage of this protocol is that WIFI networks are very common in office buildings and homes, although it is not optimized for control applications.

Energy trading protocols

According to the current evolution toward Smartgrids, different initiatives are emerging to develop the communication protocols that will make possible the interaction between buildings and ESCO/utilities. The main standardization initiatives in this area are:

- IEC 61850: This standard was originally defined for the design of electrical substation automation, but some organizations, as EPRI, are working in its evolution to support the integration of buildings in the smartgrid,
- DLMS-COSEM: It is the common language for Automatic Meter Reading, or more general - Demand Side Management.

3.5.4 Knowledge sharing

Access to knowledge

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.

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.

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.

Knowledge management

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.

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.

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.

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.

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.

Knowledge repositories

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.

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.

Personalisation: By means of user profiling the catalogues are able to provide customised information regarding both contents and presentation (format).

Knowledge mining and semantic search

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).

Log term data archival

Building life time is in the order of 100 years. Archived data may become non-accessible in a a period like ~10 years due to: lack of devices that can read old storage media, new versions of the software that was used to create it, or evolution of the format standard. The vision is that archived data will be accessible after very long periods of time. This will be enabled by BIM standards, general archiving standards and services.

3.5.5 Virtualisation of built environment

Virtual workspaces: Single global virtual workspace integrates communication and all project and business applications, including those used at the construction site [66].

Virtualisation is the 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. The virtual replacement for a physical process utilises far less energy but still enables people to achieve the same ends [46].

Office optimization

ICT technologies help companies to restructure their office environment so that the use of available space is optimised, temporarily unused space can be divested, and by this the energy consumption per employee and the total energy consumption can be reduced by up to 50%. Possible methods include replacing desktops with notebooks, stationary phones with cordless substitutes, copy, print and fax facilities with pooled, multifunctional devices, etc [47].

Further demonstrable energy reductions are possible by combining the office concept with:
- new business concepts (e.g. e-commerce, e-banking, etc); and
- new management concepts (e.g. home-working, tele-working, flexible working hours, and mobile-working).

We envisage that future energy demands and usage will shape how our office spaces are better designed and utilised. Below are some predicted developments which ICT could play a role:

- **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. This helps to save energy and consume lesser space in an office environment.
- **Energy Harvesting** – Use of ICT to provide potential 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.

Server virtualisation technology

Server Virtualisation 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. Therefore it has created opportunities for enterprises in reducing costs (and overheads), ensuring business continuity, increasing asset utilisation, enhancing infrastructure flexibility, etc. Strategically, it is an IT catalyst for shaping buildings of the future, in terms of how IT should be procured, consumed and managed, and this could even change how business innovate and grow.

Traditionally, server virtualisation has been a main focus for large businesses. We envisage that more uptakes would be seen from smaller businesses as well over the coming years.

Server virtualisation could create a future path to emerging computing concepts such as 'Cloud Computing'. Building products that are smarter-designed, enabled by a transition to cloud computing, are linked to offer "green" (or energy efficiency) benefits to buildings, infrastructure and policy-making [94].

4 Conclusions

This report is the first one in a series of REEB WP4 deliverables: Vision, Roadmap, Implementation recommendations and a Book summarising all results. It aims to address the needs of numerous stakeholders throughout the entire building life cycle, covering both specific end-applications and integration of various applications, systems and technologies. Consequently 5 high level priority areas for RTD are identified:

- Integrated design and production management
- Intelligent and integrated control
- User awareness and decision support
- Energy management & trading
- Integration technologies

The next report of REEB WP4, the "Roadmap", will propose specific RTD challenges in these areas in short, medium and long term. For each "main RTD category" the following will be presented:

- **Key research topics:** Short description of the main RTD topic(s) in this category. These will be broken down into more detail level as short-medium-long term "technology steps" in the roadmap below.
- **Vision:** Description of target future technology and its use *(summary based on this report with possible updates).*
- **Drivers:** Description of a market or policy trend that generates the need for new technologies and motivates RTD. Drivers are external factors that are not affected by this RTD roadmap.
- **Barriers:** Description of a constraint that limits or prevents the development or exploitation of new technologies.
- **Impacts:** Expected benefits and/or opportunities to key stakeholders (in ICT and construction) from using the results of the proposed RTD.
- **Scenarios:** Description of exemplary possible future situations where some of the anticipated new technologies will be in use. Refer to the key stakeholders, their roles, tools and benefits to them. The scenarios could be based on the "generic best practices" describing a similar situation using the envisaged future technologies.
- **Roadmap:** Anticipated RTD steps in the key research areas in short, medium and long term. This will be presented as a graphical diagram or in an equivalent tabular form.
- **Explanation** of all items in the roadmap.

A key finding so far is: While there is an emerging consensus about the key RTD issues in ICT enabled energy efficiency of buildings, the potential impact of various technologies is not sufficiently well known. Thereby it is difficult to assess the relative importance of specific technologies, applications and systems. It is necessary to develop a more holistic understanding of the potential effects of ICT on the energy efficiency of buildings.

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Appendix: Related activities

The appendix was prepared in the early stage of REEB WP4 as background information about relevant related activities for developing the Vision and the Roadmap. Only minor updates have been done during the preparation of WP4 deliverables.