Roadmap enabling ICT to improve energy efficiency in the built environment

F. Fouchal[1], K.A. Ellis[2], T. M. Hassan[3], S. K. Firth[4]

Abstract

Information and Communication Technologies (ICTs) are today pervasive to all industrial sectors which are faced with a sustainability paradox in maintaining economic growth while consuming fewer resources. ICTs have proven central to the performance driven development of modern industry in supporting production systems at all levels. ICTs have a unique opportunity to address the sustainability paradox by enabling Energy Efficient (EE) viable operations. However, often the issue is not a lack of technological options, but rather it is the understanding of what choices will lead to the greatest impact. This paper summarises the outcome of the research work undertaken within REViSITE (Roadmap Enabling Vision and Strategy for ICT-enabled EE), an EU funded project covering migration pathways from the current state of the art to the common vision for ICT-enabled EE. These pathways are based on research and technology development (RTD) topics for short, medium and long term delivery in terms of industrial take-up. The developed multi-disciplinary strategic research agenda (SRA) suggested research priorities in the domain of ICTs for EE, especially considered for the built environment, and its interaction with energy grids, manufacturing and lighting. The corresponding Implementation Action Plan (IAP) is given in the form of recommendations and suggestions for research development and other actions (for policy makers and regulators, RTD funding organisations, industry, education and training institutes) in the domain of ICT for EE. It is also expected that the identified RTD topics will be relevant also to many other sectors which contribute to improving the impact of ICTs on EE.

Keywords: ICT4EE, Energy Efficiency, smart Building

1. Introduction

Energy efficiency is paramount in ensuring the energy security and sustainability of Europe, and Information and Communication Technology (ICT) has a fundamental role to play in

[1] Dr Farid Fouchal, CBE, Loughborough University, LE11 3TU, UK, F.Fouchal@Lboro.ac.uk

[2] Mr Keith Ellis, Intel Labs, Leixlip, Ireland, keith.a.ellis@Intel.com

[3] Professor Tarek Hassan, CBE, Loughborough University, LE11 3TU, UK, T.Hassan@Lboro.ac.uk

[4] Dr Steven Firth, CBE, Loughborough University, LE11 3TU, UK, S.K.Firth@lboro.ac.uk

delivering that energy efficiency (Barroso, 2008; Barroso, 2011; EU commission, 2009). However, while the enabling role of ICT is clear, understanding which technologies are best positioned to deliver meaningful impact and where future research and associated funding should be directed is less clear.

The goal of the research work described here was to develop the REViSITE (Roadmap Enabling Vision and Strategy for ICT-enabled EE), it is a roadmap that identifies common research priorities in the domain of ICT for Energy Efficiency (ICT4EE). The whole project focused on four target sectors—Grids, Manufacturing, Buildings, and Lighting—and sought to develop a generic mean of assessing the impact of ICT across these sectors, however in this paper, a particular view point for the building sector perspective is drawn, discussed and recommendation for implementation are proposed. By leveraging the heuristic and domain expertise of different stakeholders, the project sought to: i) outline a common vision for multidisciplinary, ICT-enabled energy efficiency; ii) identify a strategic research agenda (SRA) focused on critical, cross-sectoral research pathways; and iii) develop the associated implementation action plan (IAP) to address those research trajectories. This was achieved through the involvement and contribution of many stakeholders across the four sectors, drawing on the combined expertise of the Expert Group, the direct contributors to this report and the ICT4EE community at large.

2. Methodology

This section summarises the methodology used in developing such cross-sectoral ICT4EE trajectories for tools and systems that are generic and can serve different industry sectors with no or reasonable adaptation.

2.1 Life Cycle Thinking

Assessment of best practice (Ellis, 2010; VDI Directive 4499, 2008; Stark, 2010) suggests that the capacity to quantitatively assess ICT impact, while desirable, is in practice an arduous task. Situations where an existing system and a replacement ICT-enabled system can be directly measured are not very common. Where this does arise, the task is often complicated by the fact that the replacement system frequently differs from the old in more ways than just the ICT element. For this reason, it can be difficult to apportion energy savings as being ICT-enabled or otherwise. Abstracting this information further to the sector level is an even more onerous process. In short, determining if the energy savings are solely attributable to a change in ICT is difficult.

In scenarios where the opportunity for direct quantitative comparison is limited, some form of heuristics-based approach is typically used for estimating. In such situations, part-measurement, secondary data, specialist knowledge, etc., all play a part. Consistent with that approach REViSITE developed a qualitative-based framework to identify the RTD strategies and ICT implementations most likely to have a positive impact on energy efficiency.

The REViSITE framework, shown in Figure 1, was based on a combination of 'Life Cycle Thinking' and on an adapted 'Capability Maturity Framework' (CMF). It used a 'triangulation' approach to assess the impact of ICT by combining heuristics obtained from domain experts with data available from quantitative and qualitative sources. (Ellis, 2011; Web 1, 2012)

2.1 Adapted Capability Maturity Framework / REViSITE Framework

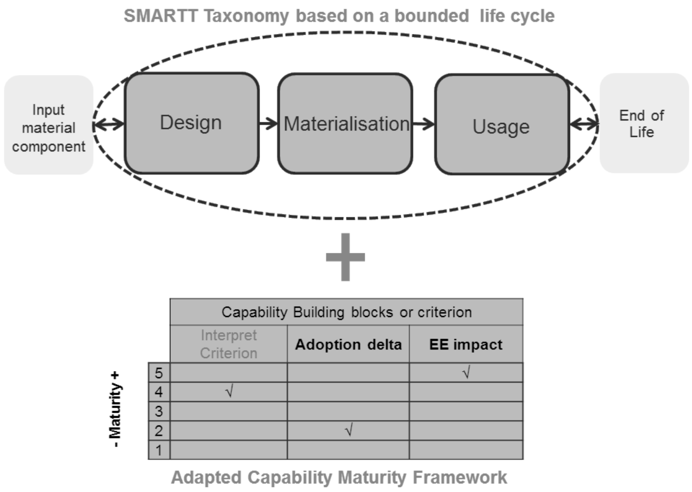

Figure 1: REViSITE framework

2.2 SMARTT Taxonomy

But, before the building sector and the other three target sectors could begin to make comparisons across their respective domains, it was essential to first speak a common technical language (Hesselbach, 2008). The first stage of framework development focused therefore on developing a common taxonomy. The output was the SMARTT taxonomy, which comprised six high-level categories (the dashed lines in Figure 2) and 23 sub-categories (as shown in Figure 3), which together were deemed to cover the scope of the ICT4EE domain. The high-level categories were aligned to the generic, bounded life cycle shown in Figure 1. Both the categories and the sub-categories were fixed, allowing for common categorisation of ICT and RTD strategies across sectors. Sector RTD/ICT topics, defined by the partners, and were nested within the sub-categories.

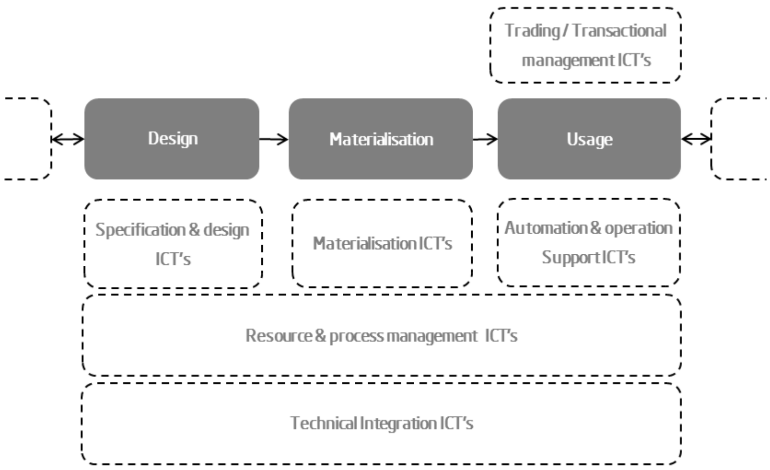

Figure 2: SMARTT taxonomy categories mapped to life cycle phases

The full SMARTT taxonomy is shown in Figure 3. The SMARTT taxonomy was used throughout the investigation as an integrative classification system and as an aid to cross-sector ICT4EE assessment. (Web:1 , 2012)

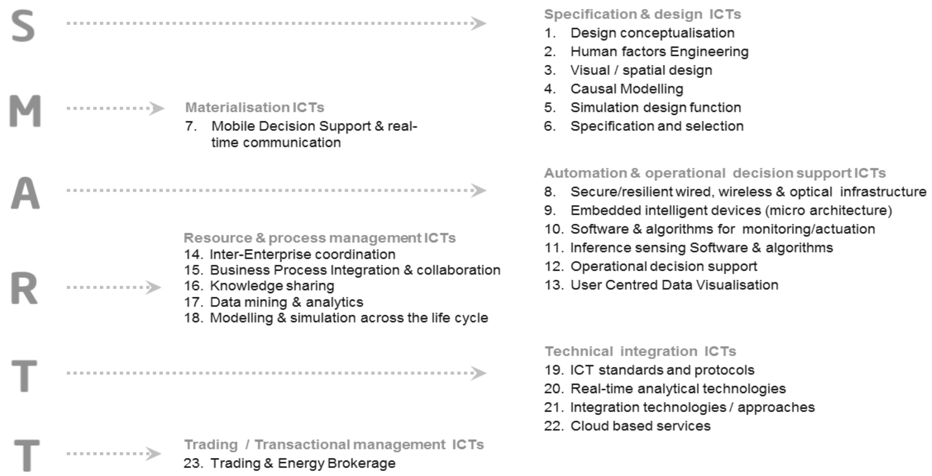

Figure 3: SMARTT taxonomy categories and sub-categories

2.3 REViSITE Framework and SMARTT Taxonomy to Identify Research Themes

The adapted CMF was used to assess how relevant each theme was in terms of defining a strategic research agenda (SRA). An online questionnaire was distributed to individual respondents (which corresponds to 23 valid respondents), who assessed the 23 ICT themes based on a combination of heuristics and domain expertise. During the subsequent analysis, each theme was mapped to a score based on the CMF-derived impact and adoption maturity scale shown in Figure 4. This enabled us to build sector-specific views about the theme's relevance to a strategic research agenda, where 'relevance' was determined using the formula:

Potential Impact Score * [Potential Adoption Score – Current Adoption Score]

2.4 Strategic Research Agenda (SRA) development

Based on the relevance of the themes as explained in the previous section, the Strategic Research Agenda suggest research priorities in the domain of ICT for Energy Efficiency across the building sector and the other three sectors. It should be noted that different sectors will invariably represent different maturity levels with respect to the technologies outlined, however the aim is to produce a holistic cross-sectorial view. 6 'roadmap' tables based on the 6 main categories and 21 sub-categories of the REViSITE SMARTT taxonomy were provided and summarised in the following section, these include: (i) State of the art; (ii) Short-term research priorities (~3 years to industrial usage; adaptation, testing and take up of new technologies, etc.); (iii) Medium-term research priorities (~6 years to industrial usage; development of new applications and incremental technologies, etc.); (iv) Long-term research priorities (~9 years to industrial usage; radical technical developments, etc.) and (v) Vision (~desirable future situation based on currently foreseen developments). Figure 4 shows a table summarising these information.

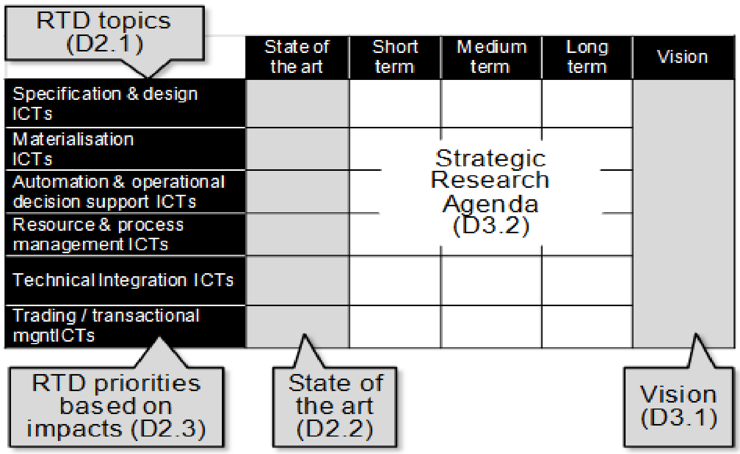

Figure 4 – Development of the Strategic Research Agenda

The SRA presented in this paper which is essentially based on the RTD topics (taxonomy) was exposed to comments by external experts in several iterations.

3. Outputs

The main body of the survey was based on rating the 'potential impact', 'potential adoption' and 'current adoption' of the 23 themes relative to energy efficiency or energy consumption reduction in each sector. The 23 themes are based on the SMARTT taxonomy. It was necessary to separate out some ICT themes for the purpose of the survey.

The survey data was extracted into matrix format, the pattern/trend analysis utilised standard mathematics, conditional formatting and re-orderable matrices [6]. This technique allowed us to separate out overall trends while also allowing for identification of difference across themes.

The output which corresponds for the built environment is outlined in the sections below. Not reported in this paper, similar work was undertaken to present the output for the other three sectors [7]. This task is followed by a trend analysis of common patterns between the sectors. The analysis is based on responses from a total of ninety-five respondents, who were surveyed and the valid response rate was 24%, making a total of valid responses equal to 23 (Building =10, Manufacturing =5, Grids = 4, and Lighting = 4).

The analysis was considered useful for SRA development and discussion. The following sub-section begins with a sector specific trend graph (see Figure 5). In all other cases (not reported here for the other sectors) the following applies:

- Column 1 – is the SMARTT taxonomy category identifier
- Column 2 – is the associated sub-category ICT theme no.
- Column 3 – is the potential impact score 'P imp',
- Column 4 – is the potential adoption score 'P Adopt',
- Column 5 – is the current adoption score 'C Adopt'
- Column 6 – is the Potential SRA Relevance score 'P SRA Relevance'.

To calculate 'P SRA Relevance' for each theme 'P imp' was multiplied by 'P Adopt' minus 'C Adopt' i.e. P SRA = P Imp * (P Adopt- C Adopt).

3.1 Key RTD/ICTs for Buildings

		Maturity Scores			
		P Imp	P adopt	C Adopt	P SRA Relevance
TE	20	4.25	4.25	1.50	11.69
TE	23	4.00	4.25	1.38	11.50
R	17	4.75	4.13	1.75	11.28
A	12	4.25	4.00	1.75	9.56
S	2	4.38	3.88	1.88	8.75
A	9	4.25	3.63	1.75	7.97
R	18	4.13	3.88	2.00	7.73
S	5	4.63	4.13	2.50	7.52
S	6	4.00	4.25	2.50	7.00
A	11	3.63	3.63	1.75	6.80
M	7	4.00	3.50	1.88	6.50
A	8	4.00	3.88	2.25	6.50
A	10	4.00	3.75	2.13	6.50
S	3	4.25	4.50	3.13	5.84
A	13	3.75	3.63	2.13	5.63
TE	21	3.00	3.25	1.50	5.25
R	14	3.50	3.13	1.63	5.25
TR	19	3.50	3.25	1.75	5.25
TE	22	3.38	3.25	1.75	5.06
S	4	3.50	3.13	2.00	3.94
R	15	3.25	3.63	2.63	3.25
R	16	3.25	3.00	2.25	2.44
S	1	3.13	2.75	2.00	2.34

SRA [Relevance] = P Imp * (P Adopt - C Adopt)

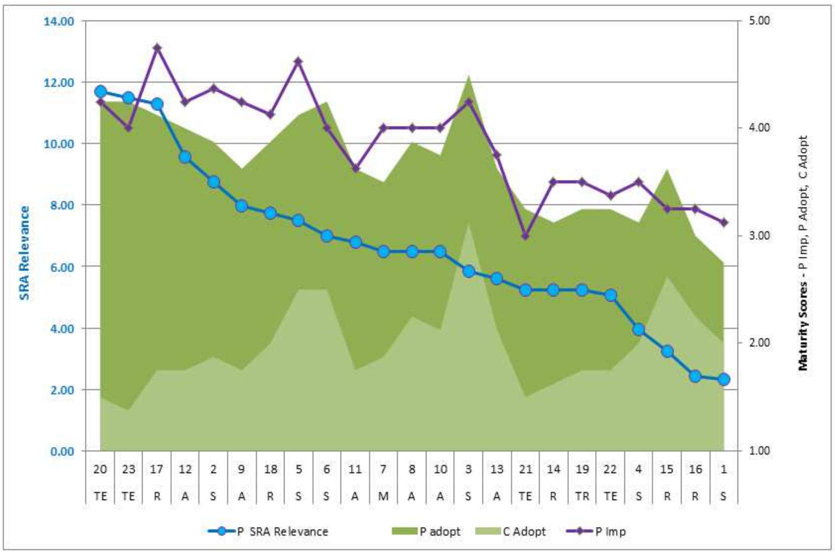

Figure 5 – Built environment ranking table and graph [10 respondents]

In figures 5 the blue (lower) line graph helps to visualise the importance of the x-axis which is relevance ranking in the context of SRA development. The purple (higher up) line indicates the specific ‘P Impact’ scores for each of those themes. The area graphed backdrop indicates the delta between current and potential adoption.

The 23 ICT themes are ranked in terms of greatest SRA Relevance to lowest. The top 11 themes are highlighted. Highlighting the top 11 scores is not to say other themes are to be ignored and is merely to guide conversation in terms of prioritisation. The column furthest right indicates the sector with the highest current adoption of each theme. This may be useful as a reference point for any research into that specific theme by the scoring sector.

The delta between current adoption and potential adoption is indicated in the column immediately to the left. While this is an obvious influencer of the overall ‘P SRA relevance’ calculation it is useful as a visual clue to the potential appropriateness of individual themes is in terms of SRA development.

4. Analysis and discussion

Having established individual sector trends we set about trying to understand common patterns amongst the sectors and try to inform on how building sector can learn from best practice of ICT applications in other sectors.

Using the re-orderable matrix technique we developed the matrices and corresponding graphs of figures 6, 7 and 8. Again the benefit of this technique is that it enables identification of overall trends while allowing for identification of variation within individual themes. ICT theme numbers together with the corresponding SMARTT category indicators [i.e. the first two columns of the table of figure] were hidden during this process to minimise influencing pattern generation.

		Light Potential Impact	Grids Potential Impact	MFG Potential Impact	Built E Potential Impact
R	15	2.67	2.75	2.75	3.25
S	1	3.33	2.25	2.75	3.13
S	3	2.33	2.25	3.50	4.25
TE	21	2.33	3.25	4.00	3.00
TE	23	2.00	3.50	3.25	4.00
TE	22	2.67	3.25	3.50	3.38
R	16	3.00	3.00	3.75	3.25
TR	19	2.33	3.75	3.50	3.50
S	4	3.00	3.00	4.00	3.50
A	13	3.00	3.50	3.75	3.75
M	7	2.33	4.25	3.25	4.00
R	14	2.33	4.25	3.75	3.50
TE	20	3.33	3.25	3.50	4.25
S	6	3.33	3.00	4.50	4.00
A	11	3.00	4.00	4.50	3.63
S	2	3.67	4.00	3.25	4.38
R	18	3.33	4.00	4.25	4.13
S	5	3.00	3.75	4.50	4.63
A	8	4.33	3.75	4.00	4.00
A	10	3.67	4.00	4.50	4.00
R	17	3.67	3.50	4.50	4.75
A	12	4.33	4.00	4.00	4.25
A	9	4.33	3.75	4.75	4.25

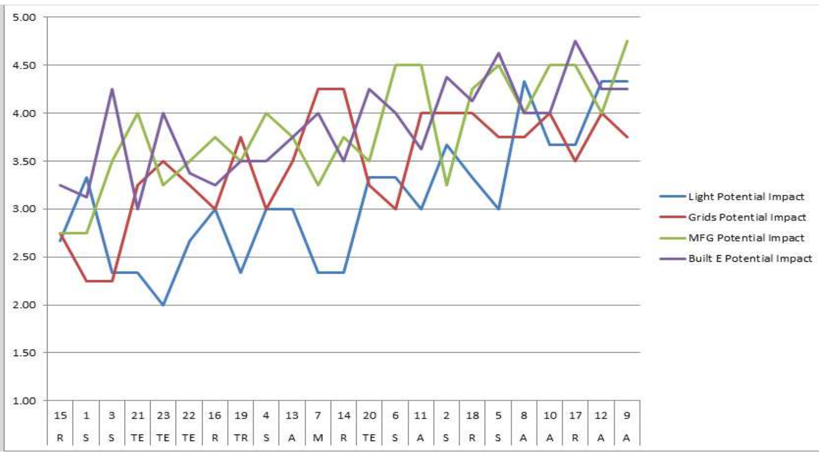

Figure 6 – Potential impact trend all 4 sectors

		Light Potential Adoption	Grids Potential Adoption	Built E Potential Adoption	MFG Potential Adoption
S	1	3.33	3.00	2.75	3.75
M	7	2.00	4.00	3.50	3.50
TR	19	2.33	4.00	3.25	3.75
R	16	3.33	3.00	3.00	4.00
TE	22	2.67	3.50	3.25	4.00
TE	21	3.00	3.25	3.25	4.00
R	14	2.67	3.50	3.13	4.25
R	15	2.67	3.50	3.63	4.25
S	4	3.67	3.50	3.13	4.00
S	6	3.33	2.75	4.25	4.00
TE	23	2.67	3.75	4.25	3.75
S	3	3.33	2.75	4.50	4.00
S	2	3.33	4.25	3.88	3.75
A	11	3.00	4.00	3.63	4.75
R	18	3.33	3.75	3.88	4.50
R	17	3.67	3.50	4.13	4.25
TE	20	3.67	3.75	4.25	4.00
S	5	3.33	4.25	4.13	4.00
A	13	3.33	4.50	3.63	4.25
A	8	3.67	4.00	3.88	4.25
A	12	4.00	4.00	4.00	4.25
A	9	4.33	4.00	3.63	4.50
A	10	4.33	4.25	3.75	4.50

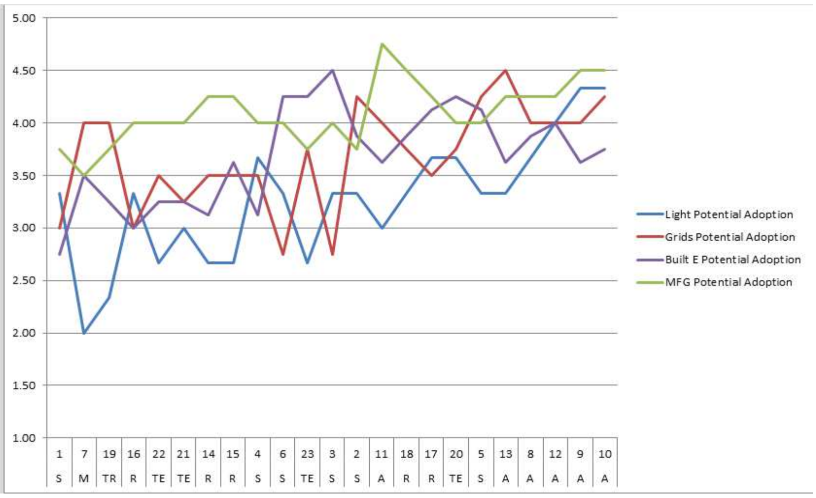

Figure 7 – Potential adoption trend all 4 sectors

		Light Current Adoption	Built E Current Adoption	MFG Current Adoption	Grids Current Adoption
TE	23	1.33	1.38	1.50	2.50
A	12	1.33	1.75	1.75	2.50
S	2	1.33	1.88	2.00	2.25
TR	19	1.00	1.75	1.25	3.50
TE	22	1.00	1.75	2.50	2.25
A	11	1.33	1.75	1.75	3.00
A	13	1.33	2.13	2.25	2.50
R	14	2.33	1.63	2.25	2.25
TE	21	2.00	1.50	2.00	3.00
R	16	1.33	2.25	2.50	2.50
M	7	2.00	1.88	2.00	2.75
R	17	2.33	1.75	2.00	2.75
A	9	2.00	1.75	2.50	2.75
S	1	2.00	2.00	3.25	2.25
S	4	2.00	2.00	3.00	2.50
S	6	2.33	2.50	2.25	2.50
A	10	2.33	2.13	2.25	3.00
TE	20	3.00	1.50	2.75	3.00
R	18	2.67	2.00	3.25	2.50
A	8	3.00	2.25	2.50	3.25
S	5	2.67	2.50	3.00	3.00
R	15	2.67	2.63	3.25	3.00
S	3	3.00	3.13	3.75	2.25

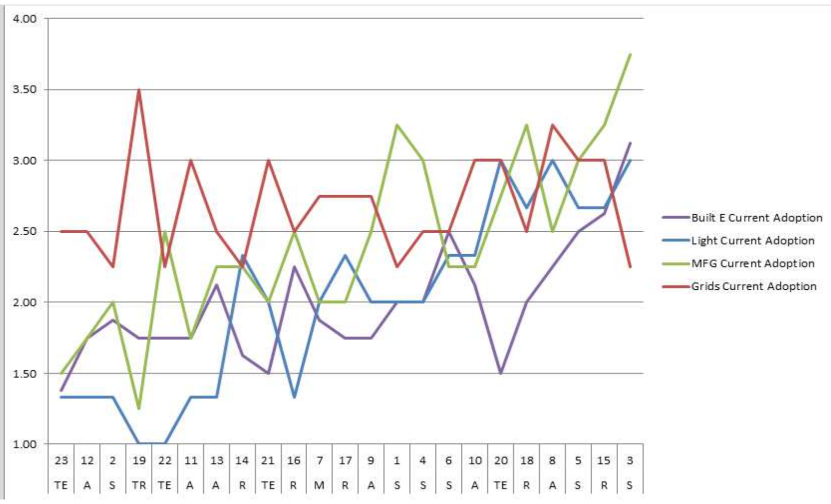

Figure 8 – Current adoption trend all 4 sectors

Based on the interpretation of the cross-sector themes ranked in terms of 'P SRA relevance'. figure 9 is the overall resulting output from the exercise and offers a prioritised list of ICT themes to be considered, while figure 10 is a an un-sorted histogram comparing SRA relevance across the sectors.

SMARTT cat.	ICT Theme no.	ICT Theme description	adoption delta
A	12	Operational decision support ICTs that integrate high level diverse systems such as safety, security, weather and energy etc. at individual, building or district level for near real-time decision making	2.23
A	9	Embedded intelligent devices (micro architecture)for operational control, sensing & actuation at machine, plant or building level	1.86
S	2	Human factors Engineering ICTs to gather and model data describing the behaviour of end users/energy consumers	1.94
A	11	Inference sensing Software & algorithms for pattern & signal identification at machine, plant or building level	1.89
A	10	Software & algorithms for operational monitoring & actuation of devices at machine, plant or building level	1.78
R	17	ICTs for data mining & analytics in terms of energy consumption & optimisation, pattern identification, predictive diagnostics & analytics at enterprise or network level	1.68
A	13	User Centred Data Visualisation ICTs to support system state awareness by human operators / users	1.88
Te	23	Use of cloud based services for tasks such as data management, monitoring and analysis	1.93
Te	20	ICT standards and protocols for interoperability across heterogeneous devices at an enterprise, network or environmental level	1.35
R	18	Modelling & simulation ICTs e.g. What-if scenario planning continuous improvement across a sectors life cycle	1.26
A	8	Secure/resilient wired, wireless and optical infrastructure for operational communication, monitoring & control	1.20
Tr	19	Trading & Energy Brokerage ICTs e.g. Consumer/Producer forecasting algorithms, energy source tracking, consumption/price negotiation	1.46
S	6	Product/component specification and selection ICTs E.G. material characteristic database specifying embedded energy, recyclability, thermal performance etc.	1.19
R	14	Inter-Enterprise ICTs for supporting coordination e.g. contract & supply-network management in the context of reduced energy consumption	1.27
Te	22	Integration technologies / approaches such as service orientation and event driven architectures to facilitate heterogeneous device data interoperability at enterprise, network and environment level	1.48
S	5	Simulation ICTs for predicting/estimating the dynamic behaviour of a system as part of the design function E.G. Computational Fluid dynamics, Finite element mode analysis, power system simulation etc.	1.14
M	7	Mobile Decision Support ICTs that utilise real-time communication to facilitate in the field decision making particularly in construction or civil engineering tasks	1.09
Te	21	Real-time analytical technologies such as Complex Event Processing and in-memory databases for enhanced operational control and awareness	1.25
S	4	Causal Modelling ICTs used to describe / predict relationships in physical systems E.G. computer-aided diagramming (e.g. Sankey, Cause and effect, influence diagrams etc.), Life cycle modelling, statistical packages such as JMP & MatLab etc.	1.20
R	16	Knowledge sharing ICTs, knowledge management, knowledge repositories, knowledge mining and semantic search, linked data, long-term data archival and recovery at enterprise or inter-enterprise level	1.19
S	1	Design conceptualisation ICTs for requirement engineering & ideation. E.G. Quality Function Deployment, Mind maps etc.	0.83
S	3	Visual / spatial design ICTs E.G. CAD (Autodesk, 3D studio max), Multimedia (e.g. Flash, Silverlight), Graphics (e.g. Photoshop, Illustrator) for digital mock-up etc.	0.61
R	15	Business Process Integration & collaboration ICTs E.g. collaboration support, groupware tools, electronic conferencing, social-media, etc.	0.63

Figure 9 – Cross-Sectorial SRA themes ranked in terms of potential relevance

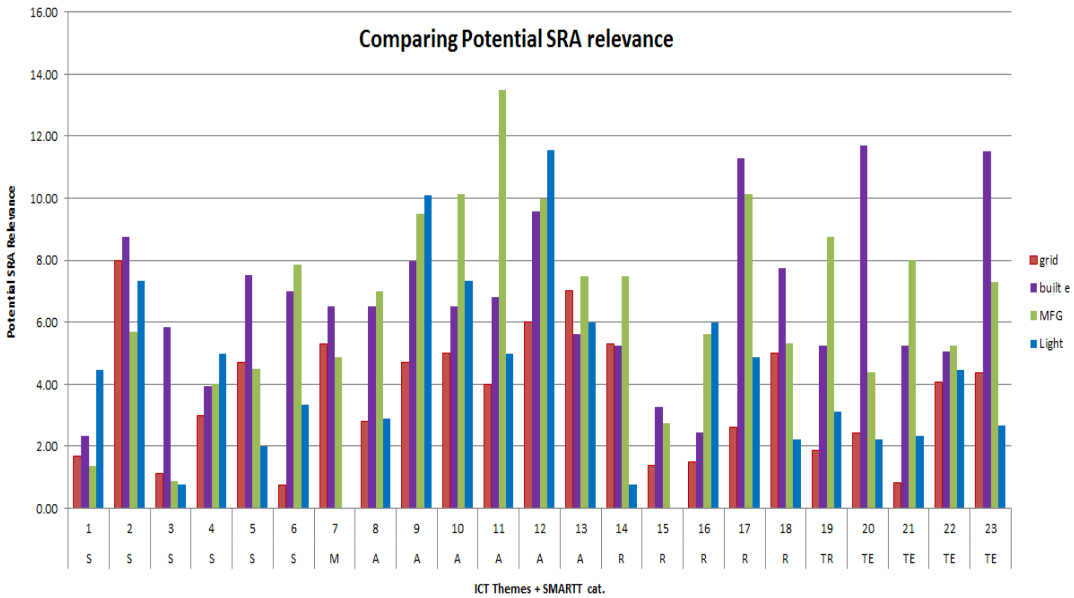

Figure 10 – Comparing Potential SRA relevance between sectors [unsorted]

The impacts of ICT on energy efficiency are subject to complex causal interdependencies of many different systems over several life cycle stages. This fact in itself calls for research to model and quantify ICT impacts for decision making about investments in ICT research and use.

The findings discussed so far were ultimately formulated into the Strategic Research Agenda which is based on the taxonomy categorisation and also follows the trends summarised in figure 9 and 10. The high level synthesis of the SRA findings are given in the following under the six SMARTT taxonomy categories, while details of the full SRA is available at (Web: 1, 2012)

4.1 The Strategic Research agenda

Specification and design ICTs: Design is central given estimates that a major share *(indicatively ~80%)* of a products *(e.g. buildings)* life time environmental impact is determined in the design phase. This is especially the case when new products/systems are designed. However, design for retrofitting of existing systems is also crucial as many products/systems are renewed several times throughout their life time. The degree, to which the designed energy efficiency potential will be actually materialised, depends on the downstream life cycle stages *(materialisation, operation).* Therefore integration between different stakeholders and stages is of fundamental importance for design. The main trend in this area is “integrated design” implying interoperability of various ICT applications and sharing of information at high semantic level between stakeholders over all life cycle stages.

Materialisation ICTs: ‘Materialisation’ follows the design phase and is a non-sector specific term understood within REViSITE to encompass construction, grid infrastructure and production-system development i.e. realisation of the physical. ICTs in this space are similar, identical in most cases to decision support ICTs in the operational phase. What is different is the context, which undoubtedly has greater significance for, but is not limited to, the construction sector.

Automation and operational decision support ICTs: This category, given its direct relationship to the operational phase of the respective sector life cycles, is probably the most obvious in considering impact on energy efficiency, especially in the context of existing buildings, production systems and grid infrastructure.

Resource and process management ICTs: This category focuses on supporting holistic EE management and decision making regarding processes/resources that span LC phases, organisational functions and indeed organisations.

Technical Integration ICTs: Semantic interoperability and technical integration are central to a holistic energy management strategy and arguable links to all categories and subcategories of ICTs. Semantic interoperability is equally as important as technical integration, but the main focus from a technical perspective is integration technologies / ICTs.

The trading/transactional management ICTs: This category relates to technologies and practices required to support an economic negotiation driven relationship between energy grids (both regulated operators and competitive market parties) and prosumers in both the manufacturing and building/lighting domains. The topic has been divided and described in terms of four energy management levels. The SRA table for the “The trading/transactional management ICTs” which includes the detailed result is given in Appendix 1 (see table 6).

4.2 Recommendations - Implementation Action Plan

The SRA was extended to much more tangible recommendations given into the form of an Implementation Action Plan. A menu of 23 potential ICT4EE research trajectories established, from the themes descried above. Attention in the following is turned to formulating the work into a format that clearly identified the 'target outcomes', 'expected impacts', and potential 'actionable items'. The interim output of the IAP work was 23 succinct tables [9] that detailed:

- The scope of each RTD topic
- The target outcomes pertaining to any future research funding call
- Expected impacts of achieving the identified target outcomes
- Specific recommendations for various stakeholders

While any of the 23 could potentially inform a research call, the research team supported by the expert group, based on their own expertise and inputs from the wider community, consolidated the 23 themes into 11 proposed call themes. The following section outlines the 11 research themes identified.

<u>Integrated Design</u>: Complex systems need to be optimised based on multiple and often conflicting criteria. The degree of energy efficiency potential that can be achieved through integrated design depends on the downstream life cycle stages (materialisation, operation). Integration between different information sources, stakeholders, and stages is, therefore, of fundamental importance for design.

The main targets for integrated design are the interoperability of various ICT applications and the ability to share information at a high semantic level between stakeholders throughout all life cycle stages; integrated design has a direct impact on both the design process itself and on the subsequent life-cycle stages which depend on design information. The energy performance of the target system depends ultimately on the combined impact of design, materialisation, and operation.

<u>Component Catalogues</u>: Catalogues of materials and components are needed to support the design of products/systems, as well as procurement for materialisation. These catalogues should provide access to various commercial and technical information (including, e.g., properties relating to energy efficiency). The catalogue content should be at an abstract/semantic level to meet the requirements of increasingly model-based design tools.

<u>Data Models</u>: Achieving energy efficiency requires holistic management of information from many stakeholders over the product's lifetime. Common concepts and language are prerequisites for communication, both between humans and ICT systems. Agreed data models (ontologies) are needed to bridge the gaps and to enable information-sharing and re-use without error-prone interpretation, manual data re-entry, and loss of data.

<u>Application Tools</u>: The main research needs are related to issues such as early-stage design and decision-making, enhancing the scope of existing tools to support design for energy efficiency, increased utilisation of existing good design solutions, information-sharing between various ICT tools through interoperability, and reducing the gap between predicted and actual energy performance of systems.

<u>Life-Cycle Energy Modelling and Estimation</u>: In early design, there is a need for planning and testing, as this has a high impact on the system's overall energy consumption. Later stages require performance indication, data processing, and visualisation, as a foundation for

management, decision-making, and control. A holistic (cross-sectoral) perspective needs new ways of integrating the different energy efficiency evaluation methodologies used across the respective sectors. Multiple new approaches are, therefore, needed to address energy efficiency metrics, measurement and analysis methods, systems integration, and knowledge repositories. Using a central hub to measure/monitor energy efficiency in buildings will help conserve energy and improve efficiency, based on market options and incentives.

Metrics and Methods for Assessing Energy Efficiency and the Impact of ICT:As discussed in previous sections, one of the primary barriers to adopting ICT for energy efficiency is assessing which solutions will have the greatest impact. Much has been done already in developing a common framework for understanding the direct impact of ICT on energy efficiency. However, while somewhat addressed in this new methodology, there is still a requirement for research to identify a) a common means of assessing the impact of ICT on energy efficiency and b) a common means of assessing energy efficiency in the first instance, as an accepted, common method does not currently exist.

Common metrics and measurement methods are required for comparison. Proposed methodologies for measurement, such as those used in residential buildings, are a good starting point, but continued research is required into ICT-enabled measurement, common assessment, verification/certification, best-practice sharing, and knowledge generation.

Data Visualisation and Decision-Support:

Compelling data visualisation and decision-support ICT will be paramount in navigating the increased volume and complexity of data, including energy and resource efficiency data at the individual, home, enterprise, and district level. In the context of future sustainable cities, there will be a need for novel data visualisation and decision-support solutions in coping with diverse, complex data and in ensuring sustained user interest/engagement. Greater volumes of heterogeneous data will require dynamically-adaptable visualisations. A basic requirement of this call theme is the expanded use of cognitive data visualisation principles. The scope of ICT solutions includes, but is not limited to, the integration of diverse systems (safety, security, weather, energy, etc.) at different levels of abstraction, SCADA, business activity modelling, management dashboards, and methodologies for analysing situation awareness in complex systems.

ICT for New Business Models and Work Practices for Improved Energy Efficiency:

There is a need for new business models and work practices to support the paradigm shift towards energy-efficient delivery of products and services throughout the whole life cycle. These may include (but are not limited to):

- New types of contractual relationships, such as performance-based contracts.
- E-commerce tools and collaborative working environments that facilitate remote working.
- Incentives for environmentally-friendly, low-carbon/energy-efficient design.
- Methods of modelling and simulation to estimate the appropriate incentive, and deliver transparent energy consumption data.

Cloud Computing and Network-Enabled Energy Services:

'Cloud computing', which encompasses Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS), is transforming the software and service industry, and will have a profound impact on the ICT strategies of multiple sectors. Much in terms of augmentation with regard to cloud computing and future networks is essentially independent of a 'sustainability [1] context. However, if not addressed, more generic issues, such as those related to adoption5 identified below, will negatively impact on cloud-based energy and resource management services, which are highly pertinent to sustainability.

The top four actions that are important to most groups (from small- and medium-sized enterprises to large enterprises) in terms of cloud computing adoption are:

- Greater accountability and liability for security by providers of cloud-based services.
- Ensuring portability between cloud services.
- Improving internet connections.
- Security certification of vendors of cloud-based services.

Add to this the important role data privacy will have for the adoption of energy-related offerings and one begins to understand the immense role context-independent issues, such as dependability, scalability, flexibility, and privacy of data, will have for energy- and resource-related services.

<u>ICT for Nodal Energy Management</u>: To describe the different nodes of the smart grid, a common model, known as a Virtual Power Plant (VPP), is used. The VPP model contains a generic set of characteristics to allow connection and interaction between the building blocks of the smart grid. The objectives of this call for research are, therefore, to investigate the different facets of the VPP model and to prepare for migration towards open platforms, which will enable energy to be managed on different scales, such as at the building level, at the district level, and at the city level, etc.

<u>Integrated Monitoring and Control for Improved Energy Efficiency</u>:

ICT solutions supporting intelligent sensing/control with respect to energy-efficient building, industrial, and grid resource automation are required. The scope of this research call includes sensing/control software and hardware, control and optimisation algorithms, embedded microcontrollers, etc.

5. Conclusions

Given the arduous nature in quantitatively assessing the impact of ICT on energy efficiency, we have posited the utilisation of an adapted capability maturity framework coupled with Life cycle thinking in leveraging the heuristics of sector experts. As a result a model outlining key ICTs with respect to energy efficiency for SRA development, and a suitable implementation action plan was devised. We believe we have achieved this aim offering a more in-depth analysis of ICT themes identified. The survey and trend analysis offers, in the opinion of the consortium, trajectories for SRA discussion. However, it must be noted that this paper does not do justice to the body of knowledge compiled during this project or to the level of effort expended by the various contributors. Altogether, the conclusion is that the target research domain consists of complementary areas that need to proceed in a balanced way in order to achieve sustainable long term impacts. The overall expectation is that ICTs will contribute to applications with higher level of semantics, knowledge sharing, system integration and interoperability. It was perceived from the analysis of the received feedback that the SRA covers the target domain with sufficient width and depth, all listed topics are regarded as relevant and important, and there is no basis for pointing out specific topics with exceptionally high or low priority.

To learn more about the REViSITE project, or to view full versions of the deliverables produced during each phase of the project, please see the project website: http://www.revisite.eu.

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