ICT for Energy Efficiency: The Case for Smart Buildings

J. Ye, T. M. Hassan & C. D. Carter
Department of Civil and Building Engineering, Loughborough University, Leicestershire, LE11 3TU, UK

A. Zarli
Centre Scientifique et Technique du Bâtiment (CSTB), Information Technologies and Knowledge Dissemination Department, CSTB BP209, 06904 Sophia Antipolis, France.

ABSTRACT: Economic growth is increasing the demand for energy. Information and Communication Technologies (ICT) have been identified to play an important role in reducing the energy intensity and increasing the energy efficiency of the European Union (EU) economy. ICT will not only improve energy efficiency and help combat climate change, they will also stimulate the development of a large leading-edge market for ICT enabled energy-efficiency technologies that will foster the competitiveness of European industry and create new business opportunities. As ICT are today pervasive to all industrial and business domains, they are expected to generate deep impacts in energy efficiency of buildings of tomorrow. Although versatile statistical information is available on energy consumption in different buildings, there is still limited understanding about the potential of ICT to reduce energy consumption. In order to put ICT at the core of the energy efficiency effort and to enable reaching its full potential, it is necessary to foster research and development (R&D) into novel ICT-based solutions and strengthen their take-up — so that the energy intensity of the economy can be further reduced by adding intelligence to components, equipment and services. In this paper, ICT based support tools to energy efficiency in the so-called smart buildings are investigated. The state-of-the-art in ICT for smart buildings is discussed with focuses on the role of ICT and key fundamental fields in which R&D efforts are needed to enable the energy efficiency in future smart buildings. Five key areas including design and simulation tools, interoperability/standards, building automation, smart metering and user-awareness tools have been identified where there is potential to improve energy efficiency through the use of ICT, and they are considered as the next generation ICT for future smart buildings. As an energy efficient housing example, the Lighthouse built in the UK is discussed in detail along with its ICT integrated building services and demonstration data of energy use. This gives a better understanding of the impacts of ICT on the energy efficiency in buildings. The paper concludes that in order to achieve the energy efficiency in buildings, further support of multidisciplinary R&D and innovation demonstrating the potential of ICT based solutions are needed to foster and accelerate the deployment of energy efficient solutions in buildings.

1 INSTRUCTION

Information and Communication Technologies (ICT) have an important role to play in reducing the energy intensity and increasing the energy efficiency of the European Union (EU) economy to mitigate the climate change globally. Recent studies found that ICT will not only improve energy efficiency and help combat climate change, they will also stimulate the development of a large leading-edge market for ICT enabled energy-efficiency technologies that will foster the competitiveness of European industry and create new business opportunities (Heras and Zarli, 2008). Statistical data has indicated that buildings account for approximately 40% of energy end-use in the EU, of which more than 50% is electrical power. As ICT are today pervasive to all industrial and business domains, they are expected to generate deep impacts on the energy efficiency of buildings of tomorrow. Here the concept of "buildings" is to be understood in a broad sense including houses, residential buildings, office buildings, large infrastructures (e.g. harbours, airports, etc.) and other facilities like tunnels. Moreover, buildings refer to all types of buildings, whether they are new, or being used or to be renovated, either they are residential, tertiary, or industrial.

Although versatile statistical information is available on energy consumption in different buildings, there is still limited understanding about the potential of ICT to reduce energy consumption. In order to put ICT at the core of the energy efficiency effort and to enable them reaching their full potential, it is necessary to foster research and development (R&D) into novel ICT-based solutions and strengthen their take-up — so that the energy intensity of the economy can be further reduced by adding intelligence to components, equipment and services. Also energy efficiency in building and construction has been recognised as one of the six main themes of stakeholder requirements identified within the Industrialised, Integrated and Intelligent Construction (I3CON) project (Ye el al. 2008). Within this context, there is a need for a shared vision and roadmap towards ICT-based innovation and optimised solutions for energy-efficiency in the built environment that will identify the ICT research, technology and development (RTD), business, and training and education needs for an appropriate migration. This is expected to be a key contribution for Europe towards world-leadership in ICT-enabled energy efficiency through intelligent solutions and in support of Europe's objective to save 20% of energy consumption by 2020, and to wide take-up of ICT-based energy systems and services for the future energy neutral and energy-positive buildings (Smart, 2008).

In this paper, ICT as an enabler to energy efficiency in the so-called smart buildings are investigated. Energy-efficient smart buildings are those buildings with an optimal management of building energy flows over the whole lifecycle, i.e. from design, construction, occupancy and through demolition and re-use. The state-of-the-art of ICT for smart buildings is discussed with focuses mainly on the role of ICT and key fundamental fields which R&D efforts are needed to enable energy efficiency in future smart buildings. Several key areas have been identified where there is potential to improve energy efficiency through the use of ICT. The RTD in these fields will lead to the next generation ICT for smart buildings. As an energy efficient housing example, the Lighthouse built in the UK is introduced along with its ICT integrated building services and demonstration data of energy use. This gives a better understanding of the impacts of ICT on the energy efficiency in buildings. The paper concludes that in order to achieve the energy efficiency in buildings, further support of multidisciplinary R&D and innovation demonstrating the potential of ICT based solutions are needed to foster and accelerate the deployment of energy efficient solutions in buildings.

2 STATE OF THE ART OF ICT FOR SMART BUILDINGS

2.1 *The role of ICT*

The potential of ICT to improve energy efficiency is generally accepted (REEB, 2008). However, in the absence of specific policy measures, to coordinate fragmented efforts and to incentivise action, this potential may not be realised in the timeframe of the EU 2020 targets (COM, 2008a; COM, 2008b). ICT have a dual contribution to make, namely, the enabling role of ICT and the quantifying role of ICT.

2.1.1 *The enabling role of ICT*

ICT can enable energy efficiency improvements by reducing the amount of energy required to deliver a given product or service:

- By monitoring and directly managing energy consumption, ICT can enable efficiency improvements in major energy-using sectors. Recent studies suggest that this capacity can be exploited to reduce energy consumption of buildings in the EU by up to 17% (Bio, 2008).
- By providing the tools for more energy-efficient business models, working practices and lifestyles, such as eCommerce, teleworking and eGovernment applications, and advanced collaboration technologies, ICT can reduce demand for energy and other material resources.
- By delivering innovative technologies, ICT can reduce wasteful consumption of energy (e.g. solid-state lighting is one clear example). Emerging solutions in computing such as thin client (computers without hard disk drives rely mostly on central servers for data-processing activities) , grid computing and virtualisation technologies promise to reduce redundancies existing in today's computer-based systems.

2.1.2 *The quantifying role of ICT*

ICT can provide the quantitative basis on which energy-efficient strategies can be devised, implemented and evaluated.

- Smart metering exploits the capacity of ICT to quantify energy consumption and provide appropriate information to consumers. If consumers can understand where inefficiencies come from, they can act to mitigate or eradicate them completely. In other words, smart metering will provide real-time as well as historical energy data to consumers as actionable intelligence at the right time to enable decision making. Trials with smart meters in the EU show that providing information to consumers on their actual energy consumption can lead to reductions of up to 10% (ESMA, 2008).
- ICT can also address the complexities of measuring energy performance at a system level: software tools can provide information and data on how to better configure the various elements of a system so as to optimise its overall energy performance in a cost-effective manner. With the imperative need for energy and environmentally

conscious design and planning, these software tools will spread from smaller to more complex systems, including urban areas and cities.

The enabling potential of ICT to reduce energy consumption will make a major contribution to improving energy efficiency in all sectors of the economy (e.g. smart grids, smart buildings, smart lighting, and smarting manufacturing, etc.). For example, ICT would play a major role not only in reducing losses and increasing efficiency but also in managing and controlling the ever more distributed power to ensure stability and reinforce security as well as in supporting the establishment of a well functioning electricity retail market. ICT could enable smart lighting by using advanced light emitting diodes technology combined with intelligent light management systems which will control the light output according to ambient lighting conditions or people's presence. This paper focuses mainly on ICT-enabled smart buildings, as discussed in the following sections.

2.2 *Smart buildings*

The term 'smart buildings' describes a suite of technologies used to make the design, construction and operation of buildings more efficient, applicable to both existing and new-build properties. These might include building management systems (BMS) that run heating and cooling systems according to occupants' needs or software that switches off all personal computers and monitors after everyone has gone home. BMS data can be used to identify additional opportunities for efficiency improvements. ICT can contribute to the energy efficiency potential in buildings through the application of building and energy management systems, smart metering technologies, solid-state lighting and lighting control systems, intelligent sensors and optimisation software. In view of the contribution to energy performance of many different factors, including materials and technologies, and the various potential trade-offs among them, developing a systemic understanding of the energy performance of a building is highly desirable.

The R&D targeting the energy efficiency in future smart buildings is to be developed around the following fundamental fields:

- Intelligent modules: These modules (or called units) must have embedded electronic chips, as well as the appropriate resources to achieve local computing and interact with the outside, therefore being able to manage appropriate protocols so as to acquire and supply real-time visibility into energy data.
- Efficient communications: They must allow sensors, actuators and intelligent units to communicate among them and with services over the network. They have to be based on protocols that are standardised and open. Also an agreement on high-level models of information exchange is essential in order to make different systems able to interact and understand each other even if they are not using the same communication protocol.
- Smart BMS/ECMS: Building management systems (BMS) and energy control management systems (ECMS) rely on embedded intelligent modules and efficient communications. They are to be new systems characterised not only by improved features (e.g. optimising the equation for energy efficiency/duration/cost), but being able to communicate by embedding appropriate tags (e.g. Radio frequency identification), and to improve global monitoring of complex assembling of products and equipments in the built environment. They have to potentially allow dynamic control and configuration of devices (based on strategies), through new algorithms and architectures for any configuration of smart devices (i.e. any set of such devices being interconnected) to be able to dynamically evolve according to the environment or change in a choice of a global strategy. Ultimately networks of these BMC and ECMS are to form the foundations of self-configuring home and building systems for energy efficiency, based on architectures where component-based in-house systems learn from their own use and user behaviour, and are able to adapt to new situations, locating and incorporating new functionality as required, including the potential use of pattern recognition to identify and prioritise key issues to be addressed, and to identify relevant information.
- Multimodal interactive interfaces: The ultimate objective of those interfaces is to make the in-house network as simple to use as possible. These interfaces should also be means to share ambient information spaces or ambient working environments. They should adapt to the available attention of users, avoiding overloading their 'cognitive bandwidth' with unnecessary warnings or redundant feedbacks.

The development in these fields has to be based on the current legacy and state of the art, which includes:

- Wired/wireless sensors: Lots of various remote controlled devices, with the use of such devices (heating, ventilating, and air conditioning (HVAC), lighting, audio-video equipments, etc.) being currently investigated in the built environment through preliminary deployment and experimentations. For example, presence sensors embedded in lighting, displays (e.g. televisions, computer screens and monitors, etc.) and other consumer electronic devices would reduce energy consumption by shutting off power supply when nobody uses these devices anymore in an office or home environment.

- Wired/wireless connection models and protocols: They are still under development and even more looking for harmonisation and standardisation. They aim at establishing and managing communication between intelligent modules.
- Proprietary platforms and networks: Current platforms implementing connected modules are mainly experimental platforms, with no standardisation of management of and communication between any kind of intelligent modules. There are already developments around de-facto standard platforms or execution environments, but these are still mainly at an experimental level.
- ‘Dumb’ legacy services: All services deployed by the industry so far are specialised/dedicated services that ensure one given function, without providing interoperability, and no capacity to communicate with other services or to take into account the full environment.
- Multimodal context-aware interfaces and devices: Few intelligent modules that are not intrusive and offer appropriate interfaces to allow the final user to seamlessly integrate the ubiquitous network.

Figure 1 illustrates the current state-of-the-art regarding the identified fields.

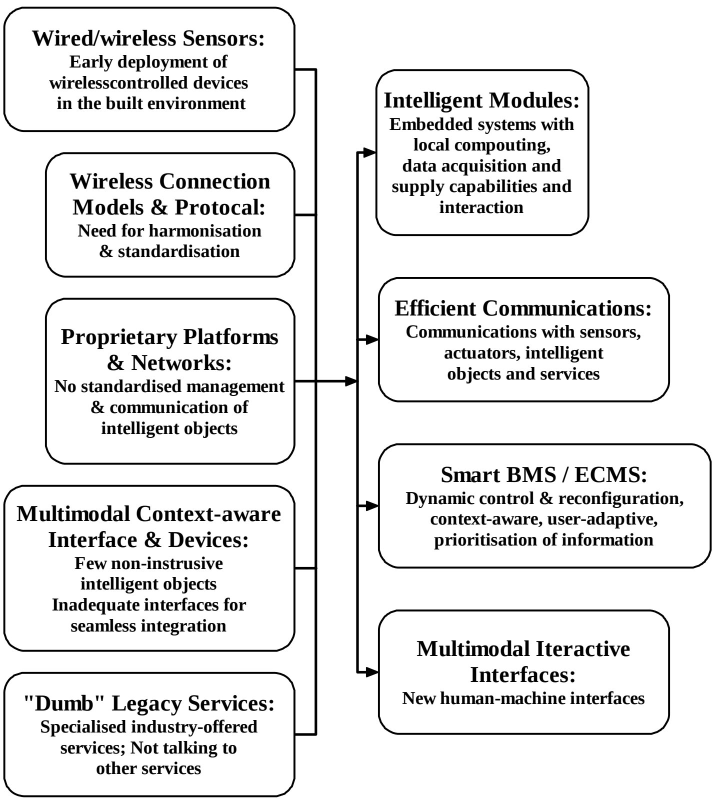

Figure 1. Technologies for smart buildings

3 DEVELOPING NEXT GENERATION ICT FOR SMART BUILDINGS

Recent researches regarding intelligent management systems inside buildings, among other ICT applications, have shown that important energy savings can be reached using these technologies (EPIS, 2007). The use of these intelligent systems inside buildings can improve the control and management of HVAC, lighting, and other “energy-hungry” devices.

Applying novel ICT solutions for control systems and building automation promises to have an impact on electricity demand at the level of households and much more at the level of publicly owned buildings which are professionally managed. Building control systems enable the integrated interaction of a number of technological elements such as HVAC, lighting, safety equipment etc. Advances in nanotechnologies, sensors, wireless communications and data processing enable embedding of ambient intelligence in building so as to reduced energy consumption. The smart building group report (Heras and Zarli, 2008) identifies five areas where there is potential to improve energy efficiency through the use of ICT.

3.1 *Design and simulation tools*

Integrating the whole lifecycle of buildings into a holistic approach to improve energy efficiency is a key demand from the stakeholders (Ye et al. 2008). The use of building information models including energy simulations across the entire life of the building will result in achieving significant improvements in buildings’ energy performance by providing monitors and sensors throughout that can help more accurately measure usage, system status and equipment conditions as well as full price information, dynamic tariff and demand response and allowing more energy efficient customer choices, value adder services and more integrated demand side automation.

Studies undertaken in Europe highlighted that designers can achieve significant improvements in building’s energy performance if they apply ICT tools to plan buildings that minimize energy consumption – e.g. simulating and optimizing envelope measures and passive solar heating techniques. In moderately cold climates, such as the ones of central Europe, for example, specific heating needs can in principle be reduced from over 200 kWh/m2/year to less than 15 kWh/ m2/year (WWF, 2008).

Although its impact is higher in new developments, design and simulation tools become an essential element in existing buildings refurbishment operations as they enable an assessment of the different solutions in order to choose the optimal one for reducing building energy demand (by including for example, renewable energy technologies).

3.2 *Interoperability/standards*

Most building control systems today are based on localised microprocessors with hardwired sensors controlling single functions. It is not unusual to have separate controllers for heating, cooling air conditioning etc. There are significant opportunities for efficiency but most are lost due to lack of integration and compatibility. The most appropriate solution would be one single control system, governing all HVAC, lighting and other electrical applications, and related sub-systems installed in a building. The main barrier to this logical solution is the fact that the different sub-systems are manufactured and often installed and even operated by different companies. Furthermore, taking into account that the lifetime of a building is much longer that of an ICT system, upgrading operations will be difficult as there is still inadequate development of standardisation for the interfaces and communication, even between the sensors and actuators.

3.3 *Building automation*

In the area of building automation, which is primarily perceived as improving life quality (e.g. more comfortable, safer homes), ICT have the potential to contribute to energy efficiency through the use of improved control and management systems based on smart appliances and communication networks. Building control systems are intended to improve the quality of comfort, health and safety conditions of indoor environments in an effective and efficient manner. In contrast to passive energy efficiency measures (e.g. insulation) and conventional heating/cooling technologies, building control systems have been introduced to ensure the integrated interaction of a much broader range of technological elements (HVAC, lighting, life safety equipment, architecture), and of humans who live/work in them in order to influence the indoor environment. Recent developments in nanotechnology (e.g. windows, surfaces), sensor/actuator technology, wireless communication technology and data processing and control have enabled the embedding of ambient intelligence in buildings.

3.4 *Smart metering*

Smart metering enables more accurate measurement of consumption via the use of advanced meters which are connected to a central unit through a communications network, improving data collection for billing purposes. The benefits of smart metering were examined in detail in the grids report (SmartGrids, 2008). Smart metering provides information on consumption patterns contributing to more sustainable consumption and energy savings.

A smart meter generally refers to a type of advanced meter that identifies consumption in greater detail than a conventional meter, and communicates this information via the network back to the local utility for monitoring and billing purposes. Using smart meters merely for data collection and billing purposes does not fully exploit their potential. In fact smart meters close the information gap for understanding energy use pattern and implementing more efficient control mechanisms. They are offering to the customers (of both electricity and gas) the following additional advantages:

- More accurate bills (i.e. avoid bills based on estimated use);
- Information that could help them use less energy and encourage investment in energy efficiency;
- Lower costs through reduced peak consumption, because this would reduce the need for new network investment;
- Increased security of supply because the less energy is used;
- More sustainable consumption through reduced carbon emissions.

3.5 *User-awareness tools*

The provision of intuitive feedback to users on real time energy consumption has significant potential to change behaviour on energy-intensive systems usage. Different studies have shown that a reduction of 5-15% of energy consumption could be achieved through the implementation of this measure (Darby, 2006).

In addition, there is a need to ensure the acceptance of embedded systems and other ICT-based solutions at home through the use of human-centric graphic interfaces for different user profiles (age, cultural level, etc.).

4 ENERGY EFFICIENT HOUSING: THE LIGHTHOUSE

The Lighthouse is the UK's first net zero carbon house that also meets Code Level 6 (the highest level) of the Code for Sustainable Homes (CSH, 2006). It was designed to provide a way of living that encourages lifestyles which are inherently 'light' on the world's resources, balancing the practical requirements of homeowners with a response to the expected climate change in the UK. The design and construction of the house proved that a carbon-free house is achievable but it places the responsibility on both the technologies (e.g. ICT and materials) and its user. It is a living experience which relies on the occupant adapting their lifestyle.

4.1 *Design*

The heart of the design concept for the Lighthouse, the prototype of which is 93 m2, two and a half storey, two bedroom house, is the ambition to create homes that are attractive; places where the environmental systems and construction methods do not compromise the quality of the occupant's life but add to it - adaptable, flexible spaces that are designed for modern living, intuitively integrating sustainability. It has been designed in line with Lifetime Homes (LTH, 2004) and Scheme Development Standards (SDS, 2003). Figure 2 illustrates the outline of the Lighthouse.

Figure 2. Outline of the Lighthouse (Kingspan, 2009)

4.2 *Structure*

The structure of the Lighthouse is a simple barnlike form, derived from a 40 degree roof accommodating a photovoltaic array (as shown in Fig. 3). The sweeping roof envelops the central space – a generous, open-plan, top-lit, double height living space, with the sleeping accommodation at ground level. The living space uses a timber portal structure so floors can be slotted between the frames or left open as required.

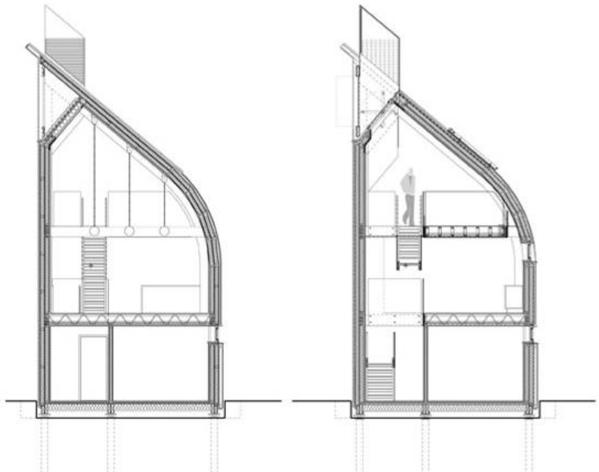

Figure 3. Structure of the Lighthouse (Kingspan, 2009)

Stability is achieved through the moment connections at first floor and ceiling level. At ground level a timber frame structural layout carries the vertical loads of the open plan frames above and provides stability to the load bearing shear walls. It is constructed using Kingspan Off-Site's TEK Building System (TEK, 2009), a high performance structurally insulated panel based system which, for the Lighthouse, will provide a high level of thermal insulation and performance – U values of 0.11W/m2K and air-tightness of less than 1.0m3/hr/m2 at 50Pa - reducing the heat loss by potentially two thirds of a standard house. The foundations consist of offsite timber floor cassettes on a ring beam of timber beams supported off the ground level by screw fast pile heads. The piles provide minimal disturbance to the ground and provide suitable supports for domestic scale dwellings. When the building reaches the end of its useful lifespan, the fast foundation support point can be removed.

4.3 *ICT integrated building services*

ICT play a major role in the building service integration in the Lighthouse. ICT-enabled smart metering and energy management system will record energy consumption and enable occupants to identify if any wastage is occurring, helping to promote more environmentally aware lifestyles.

As discussed in Section 2.1, ICT could make not only the management of power grids more efficient but also facilitate the integration of renewable energy sources. Through its integration with ICT, renewable energy is provided by a biomass boiler with an automatic feed system for heating, building integrated photovoltaic electricity and a solar-thermal array, which supplies hot water and allows the boiler to be turned off in the summer and turned down in the spring and autumn, significantly reducing fuel consumption. These renewable energy features have reduced energy fuel costs for space and water heating in the Lighthouse to around £30 per year and, as all electricity is supplied via solar technologies, electricity running costs are completely eliminated. The overall costs of the fuel has been reduced by about 94% (not including standard charges).

Lighthouse also includes mechanical ventilation with heat recovery (MVHR), as well as a roof-mounted wind catcher, which provides secure night-time ventilation for passive cooling, in conjunction with thermal mass boards in the ceilings and external shading. This helps to control the temperature of the interior environment, improving occupier comfort and keeping the house cool in the summer months.

4.4 *Energy use*

The energy use has been calculated using an adapted standard assessment procedure method (SAP, 2005). Standard assessment procedure is the calculation method used for the energy assessment for checking building regulations compliance for dwellings.

The heating energy is calculated using a degree day method. Standard assessment procedure has been adapted as follows:

- 100% low energy lighting rather than 30%
- 0% secondary heating rather than 10% electrical
- 88% heat recovery efficiency rather than 66%
- Specific fan power of 0.92 W/l/s rather than 2 W/l/s
- 2940 kWh/yr solar thermal (calculated by manufacturer) rather than 1475 kWh/yr
- Water heating based on reduced shower water flow rate

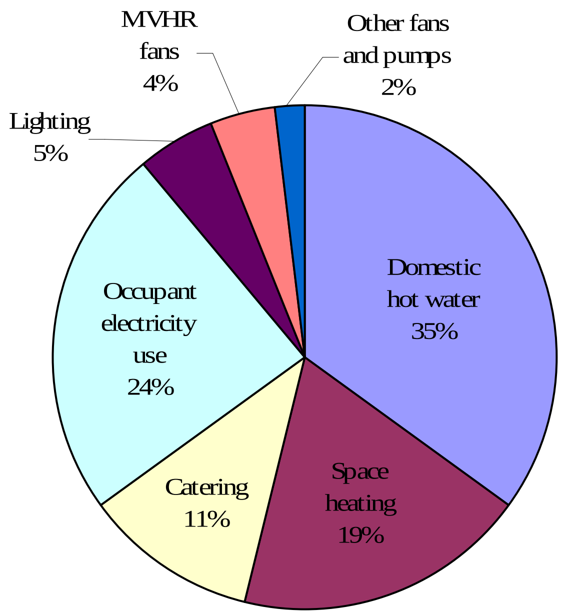

Figure 4. Lighthouse energy use

The energy cost of running the Lighthouse would be about £31 per year for the wood pellets, assuming wood pellets cost 1.8 p/ kWh. The electricity is free from the sun. A house of the same size and shape but built to 2006 building regulations standards would cost about £500 a year in energy bills. Most of the domestic hot water energy is provided by the solar thermal panels. There is a small amount of carbon dioxide emissions associated with the growing, processing and delivery of the wood pellets for the remainder of the hot water and for the space heating. This is offset by extra renewable electricity that is generated from the sun by the photovoltaic panels and exported to the grid. In this way, the house is net zero carbon on an annual basis. Figure 4 demonstrates the distribution of the Lighthouse energy use.

5 CONCLUSIONS

In this paper, ICT as an enabler to energy efficiency in the so-called smart buildings are investigated. The role of ICT is discussed along with the fundamental fields to be developed for energy efficiency in future smart buildings. Five key areas have been identified where there is potential to improve energy efficiency through the use of ICT. As an energy efficient housing example, the Lighthouse built in the UK is discussed along with its ICT integrated building services and demonstration data of energy use. In order to achieve the energy efficiency in buildings, further support of multidisciplinary R&D and innovation demonstrating the potential of ICT based solutions are needed to foster the acceleration of the deployment of energy efficient solutions in buildings. It is expected that the integration of ICT in smart buildings will significantly improve the energy efficiency within these buildings.

REFERENCES

Bio, 2008. Impacts of Information and Communication Technologies on Energy Efficiency. Available at: ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/sustainable-growth/ict4ee-final-report_en.pdf

COM, 2008a. Communication From the Commission (COM (2008) 772 Final). Available at: http://ec.europa.eu/energy/strategies/2008/doc/2008_11_ser2/com_2008_772_delivering_20_target.pdf.

COM, 2008b. Communication From the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (COM (2008) 241 final)). Available at: http://ec.europa.eu/information_society/activities/sustainable_growth/docs/com_2008_241_1_en.pdf

CSH, 2006. Code for Sustainable Homes: A Step-change in Sustainable Home Building Practice. Available at: http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf

Darby, S. 2006. The Effectiveness Of Feedback On Energy Consumption. A Review For Defra Of The Literature On Metering, Billing And Direct Displays. 2006. Available at:

http://www.defra.gov.uk/ENVIRONMENT/climatechange/uk/energy/research/pdf/energyconsump-feedback.pdf
EPIS, 2007. The Role of ICTs as Enabler for Energy Efficiency. EPIS Work Package 1 Deliverable 1.3. Available at: http://epis.jrc.ec.europa.eu/documents/Deliverables/ETU3%20Final%20Version%202.pdf
ESMA, 2008. Methodology for Estimating Energy Savings related with Smart Metering. Available at: http://www.esma-home.com/UserFiles/file/downloads/Deliverables/EN/D8%20Summary.pdf
Heras, J. & Zarli, A. 2008. The Smart Buildings Group Report on ICT for Energy Efficiency. Final Report, September, 2008.
Kingspan, 2009. The Lighthouse Project. Available at: http://www.kingspanlighthouse.com
LTH, 2004. Lifetime homes: 21st Century Living. Available at: http://www.lifetimehomes.org.uk/lifetime_docs/LTH%20Booklet.pdf
REEB, 2008. REEB Project Newsletter, Issue No. 1, October, 2008.
SAP, 2005. The Government's Standard Assessment Procedure for Energy Rating of Dwellings. Available at: http://www2.env.uea.ac.uk/gmmc/energy/env2d02/pdf/Final_SAP2005_text.pdf
SDS, 2003. Scheme Development Standards. Fifth Edition April 2003. Available at: http://www.housingcorp.gov.uk/upload/pdf/SDSv5.pdf
Smart, 2008. Smart 2020: Enabling the Low-carbon Economy in the Information Age. Available at: http://www.theclimategroup.org/assets/resources/publications/Smart2020Report.pdf
SmartGrids, 2008. ICT for Energy Efficiency in Smart Distribution Networks. Final Report, 2008. Available at: http://ec.europa.eu/information_society/eeurope/i2010/docs/high_level_group/annex_consultation_groups_all_6.pdf
TEK, 2009. Kingspan TEK Building System. Available at: http://www.kingspanoffsite.com/kingspan/storage/quality_assurance/productinfromation.pdf
WWF, 2008. The Potential Global CO2 Reductions from ICT Use. Available at: http://www.wwf.se/source.php/1183710/identifying_the_1st_billion_tonnes_ict.pdf
Ye, J. Hassan, T.M. Carter, C.D. & Kemp, L. 2008. New Demands in Construction – A Stakeholder Requirement Analysis. Proceedings of the European Conference for Process and Product Modelling (ECPPM). Sophia Antipolis, France, pp. 507-515, ISBN 978 0 415 48245 5.