ICT in the built environment: Drivers, barriers and uncertainties

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Abstract

Buildings are major contributors to energy use and environmental impact in developed societies. If the ambitious sustainability targets of modern societies are to be met, energy use in the built environment must be addressed as a central issue.

New momentum on achieving energy efficiency in the building sector has been triggered by information and communication technology (ICT). New opportunities bringing the concept of smart building closer to reality are offered e.g. by innovative sensing techniques, extensive and cost-efficient data collection and analysis, advanced controls and artificial intelligence.

However, these opportunities are associated with cost and uncertainties regarding whether the investment costs are paid back in terms of energy savings, whether indoor comfort and air quality and improved, the drawbacks in term of increased maintenance effort, complexity, reliability and resilience, the effects in terms of user interaction, how data security is affected and the long-term effects on society.

This paper critically analyses recent research findings and reviews the pros and cons of some promising ICT techniques being applied in the building sector. It exemplifies drivers and barriers to implementation of advanced controls and artificial intelligence in buildings, based on findings from two test-beds in Stockholm, and discusses the implications of these findings for future research.

Keywords: energy efficiency, information and communication technology, sustainability, built environment

1. Introduction

Buildings are estimated to account for 30% of overall energy use and 40% of CO_2 emissions in developed countries (Berardi 2013). Information and communication technology (ICT) has been shown to enable and determine energy efficiency in the built environment, e.g. through advanced controls, energy monitoring and fault detection and promotion of energy-efficient behaviours (Faruqui, Sergici and Sharif 2010; Hargreaves, Nye and Burgess 2010, 2013). It is unsurprising that smart homes are a high priority in the EU Strategic Energy Technology Action Plan (Wilson, Hargreaves and Hauxwell-Baldwin 2017).

Smart homes have been defined as home-like environments that possess ambient intelligence and automatic control, which allows them to respond to the behaviour of residents and provide them with various facilities (De Silva, Morikawa and Petra 2012). Smart homes offer potential features that go beyond the capabilities in current buildings, such as improved security, assisted living and e-health capability, augmented entertainment, communication and visualisation (e.g. with feedback on energy use), improved comfort and indoor air quality and more efficient use of energy (Balta-Ozkan et al. 2013).

Smart buildings are expected to play a relevant role as units in smart sustainable cities, and have been the object of great attention in the literature in recent years (see e.g. the review by Solaimani, Keijzer-Broers and Bouwman 2015). The present paper summarises the most recent findings in the literature concerning opportunities and challenges encountered in implementation of smart homes and illustrates the findings with examples of current research on smart buildings at the Royal Institute of Technology (KTH) in Stockholm. The following sections present a brief summary of drivers, barriers and uncertainties reported in the literature and describe experiences from two examples of smart buildings, the KTH EES Q Building Testbed and the KTH Live-In Lab, which are compared against literature findings.

2. Drivers

Smart homes can provide assisted living and home tele-health capabilities. The possibility of maintaining good health and independence for the elderly is undoubtedly among the main drivers for implementation of smart homes in societies with an ageing population. Smart homes can offer the possibility to provide assurance, enhance impaired physical functions and assess the cognitive status of the elderly, contributing to improved quality of life (Chan et al. 2009). Although home tele-health and telemedicine still seem to remain in the research domain and determination of their cost-effectiveness may require further studies (Chan et al. 2009), the evolution of technologies involved in smart homes will most likely change the way houses appear and are used (De Silva, Morikawa and Petra 2012). However, Chan et al. (2008) warn that in the past 20 years, smart homes have failed to achieve the anticipated results.

Another crucial driver for the implementation of smart homes is the potential to play a primary role in environmental sustainability through improved energy efficiency. Building automation and advanced controls have been proven to have the capability to reduce the energy demand in buildings. For instance, tests of model predictive control schemes in a university building in Prague revealed an overall heating demand reduction of between 15 and 28 % compared with the baseline controller (Prívara et al. 2011; Široký et al. 2011). Similarly, the relevant Swedish standard (SS-EN_15232: 2012) estimates that the potential energy savings deriving from building automation control systems (BACs) lie within the range 14-50% for thermal energy in non-residential buildings, and are 19% in residential buildings, when baseline and highly energy efficient BACs are compared. Highly energy efficient BACs are capable of setting appropriate indoor temperatures when people are present, maintaining indoor comfort and avoiding unnecessary energy use when indoor spaces are not used. Obviously, the energy savings from building automation and ICT vary depending on building location, geometry, materials and heating, ventilation and air conditioning (HVAC) design, but these figures are indicative of the relevant energy saving potential.

In a survey on the impact of user behaviour on energy use in buildings, Nguyen and Aiello (2013) found the experimental energy saving in lights and plug loads to be 13-25% and 14%, respectively, with higher potential when simulations were involved.

Through energy monitoring, feedback to users and automated control, smart homes have the potential to promote energy-efficient behaviours, which can reduce energy demand by 30% (Nguyen and Aiello 2013), and prevent the so-called energy rebound effect (Hens, Parijs and Deurinck 2010). Otherwise the potential energy rebound effect is estimated to be up to 30% (Haas, Auer and Biermayr 1998; Haas and Biermayr 2000).

It important to stress that the EU Energy Performance of Buildings Directive requires all new buildings to be nearly zero-energy by the end of 2020, while by 2018 all new public buildings must be nearly zero-energy (EC 2013). Building automation and energy monitoring can be a key factor in ensuring that buildings operate as designed, both when commissioned and during their life span.

3. Barriers and uncertainties

The main barriers to adoption of smart buildings are often categorised as technical, administrative and societal. Among the technical barriers are complexity, interoperability and reliability (Balta-Ozkan et al. 2013). A social challenge is the ‘fit’, which is the capability of smart homes technologies and service to be integrated into the design, lifestyle and general sense of home (Balta-Ozkan et al. 2013).

Privacy is often seen as another major barrier by both experts and users, with concerns about physical security and the risk of smart systems being hacked and data falling into the wrong hands (Balta-Ozkan et al. 2013b). Similarly, Friedewald et al. (2007) identified surveillance of users, identity theft and malicious attacks as the main risks related to privacy in smart homes.

Bulut et al. (2016) focused on the financial uncertainties in implementation of active buildings in the smart grid in Sweden, identifying high investment costs, low electricity price, lack of suitable business models to cope with investment and revenues uncertainty and the problem of ownership (i.e. who should make the investment) as main barriers among active building stakeholders.

4. Experiences from two testbeds: KTH EES Q Building Testbed and KTH Live-In Lab

A number of activities in the area of smart buildings have been initiated at KTH, with two buildings, a testbed and a living lab, being the flagship areas for testing and research. The following subsections briefly describe the building facilities and the experience gained so far.

4.1. KTH EES Q building testbed

The EES Q Building Testbed is housed on the KTH main campus, in the ground floor of a seven-story office building with a heavyweight concrete structure (Figure 1). The testbed consists of four rooms: a laboratory and three student offices. The rooms are all equipped with supervisory control and data acquisition (SCADA) and programmable logic controllers (PLCs), a wireless sensor network, an actuator network and a weather station.

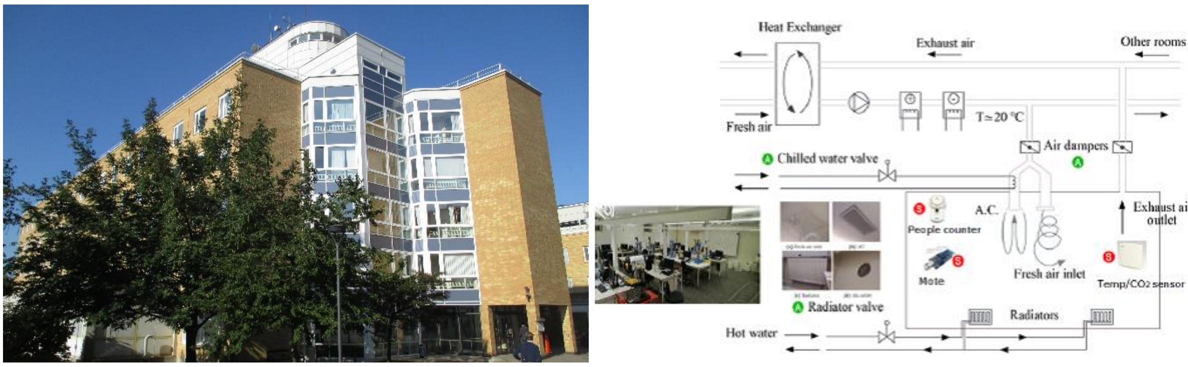

Figure 1: Building enclosure, heating and ventilation scheme of the EES Q Building Testbed at KTH.

The installed sensors enable continuous monitoring of the status of the system, e.g. room air CO_2 concentration, temperature, humidity, and external weather conditions. The implemented platform also gathers data from weather forecasting services and is integrated with web-based scheduling services (calendars) of the occupancy of the rooms. Occupancy is measured through a photoelectric-based people counter. The HVAC system of the rooms consists of a ventilation system supplying fresh air plus a radiator heating system. Air is vented from a central air handling unit with heat recovery into the rooms by a fan running by default between 8:00 and 15:00 h during weekdays. When the central fan is on, a minimum air flow is distributed into the rooms, irrespective of their occupancy, due to building regulations. The heating system uses standard waterborne radiators as heat emission units.

The EES Q Building Testbed is an experimental laboratory and the considerations here are only partially applicable to smart homes, but some conclusions and similarities with the previous literature can be identified. The main purpose of the testbed is to test innovative schemes for control to improve indoor comfort and minimise energy use in buildings. Specifically, a deterministic model predictive control and a stochastic model predictive control have been tested and compared with the standard control approach (PI controller). The results show that the proposed control approaches are capable of reliably improving indoor comfort and reducing energy use (Parisio et al. 2013, 2014). Remarkably, the full energy saving potential could not be reached due to building regulations that mandate a certain amount of ventilation in all rooms regardless of occupancy**.**

However, the encouraging results achieved in the testbed needed extensive labour inputs to properly equip the building with additional sensors, as existing sensors were designed for basic control and not suitable for accurately monitoring energy flows. It is important to stress that even if buildings are often equipped with various sensors, these are usually designed for billing or control purposes and their resolution may prove inadequate for proper monitoring, and in particular for determining how efficiently energy is used in indoor spaces with respect to occupancy and comfort. The testing of advanced controls also required a different set of software tools that needed to be combined in a tailored configuration to interoperate reliably, adding to the complexity of the project. In addition, the experimental set-up required specialist expertise to be properly maintained. A partial solution to these issues, for instance for energy monitoring, might be provided by commercial solutions in low cost computers like Arduino and Raspberry Pi and the set of libraries developed and available on the internet. In the EES Q Building Testbed, the issue of maintenance for critical applications was solved by means of redundancies, for instance by providing a simple and more reliable controller for the HVAC, to be used if the experimental controller failed, although failure did not occur.

From the point of view of energy efficiency, issues arose in the interaction between users and the system, which highlights the importance of flexible and adaptive control schemes in the building. Set points and schedules were designed for energy efficiency, for instance reducing the time during which ventilation operated to the slots in which the rooms were scheduled to be occupied. However, the rooms were often occupied beyond the expected time frame, leading to poor indoor air quality. As a reaction people tended to open the windows, causing thermal discomfort comfort due to low winter temperatures, and the windows were then often left open (no opening sensor was present), thus increasing the energy consumption when the ventilation was operative again on the following day due to bypassing of the air recovery system.

4.2. KTH Live-In Lab

The KTH Live-In Lab (Figure 2) is a platform for research, testing and education to promote innovation in the building sector and consists of both virtual and physical test environments. The Live-In Lab is housed in three residential buildings, currently under construction, for approximately 300 studio apartments located in the main campus at KTH in Stockholm, next to the EES Q Building Testbed. Heating and cooling power to the buildings is provided by ground-source heat pumps. Heat is distributed airborne to the apartments through thermally activated building slabs that provide ventilation and heat distribution at the same time. Electricity is generated locally with photovoltaic (PV) panels installed on the flat roof, and the installation of storage systems, in particular batteries for electricity, is under discussion.

The buildings comprise passive and active parts. The passive part accounts for the majority of the floor area and is designed to be extensively equipped with state-of-the art sensor devices to log indoor and outdoor environmental parameters (e.g. temperature, humidity, light etc.), primarily for continuous, real-time monitoring of indoor comfort and energy use. In the initial phase of the project, the passive part will be used only for monitoring. The active part accounts for approximately 300 m^2 of floor area and will be used for more active testing in which the experimental set-up, including the layout of the apartments in this area, will be periodically changed, allowing a holistic approach to the research on buildings. The active part has a dedicated heating and cooling system and energy is provided with a separate heat pump and boreholes. Advanced monitoring and control will be tested and fine-tuned there, and then applied to the rest of the building.

Figure 2: Computer-generated image of the Live-In Lab [source: property developer Einar Mattsson].

Although the KTH Live-In Lab is still in the construction phase, some preliminary considerations can be reported. In the design phase of a smart building, it may be difficult for all stakeholders to fully understand the potential advantages of new technologies, and simpler technologies, for instance for energy monitoring and HVAC control, may be preferred. Furthermore, there is a risk that adoption of new technologies may prove more expensive, due to the lack of necessary procedures and expertise for design, installation and maintenance.

5. Discussion and conclusions

This paper briefly reviewed some of the main drivers and challenges to implementation of smart homes identified in the literature and in ongoing research at KTH. Smart buildings offer invaluable potential, but are complex and evolving systems. To unlock their potential, it is crucial that all stakeholders (constructors, designers, users) understand their advantages and limitations. To this end, demonstration projects, testbed and semi-experimental buildings, like the KTH EES Q Building Testbed and the KTH Live-In Lab, are crucial in transferring experiences developed in testbeds to all relevant stakeholders.

Technical challenges may be addressed and fixed, but business models and the need to properly define value creation must be addressed if smart homes are to make the expected impact in the built environment. Even if energy savings per se may not always make the extra investment involved in smart buildings economically viable nowadays, sharing the same ICT infrastructure across multiple services (improved indoor control, security, telecare etc.) is likely to change this picture.

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