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Insights on Smart Home concept and occupants' interaction with building controls

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Abstract

The increasing attention for energy efficiency in buildings stimulates the expansion of "Smart buildings". In offices and homes, building automation systems are suited to individuals, foresighting their needs. Occupants' compliance is a fundamental requirement for a successful adoption of building automation systems. An important warning regards that such "smart behaviour" of the building should match with the occupants' satisfaction and their feeling of controlling the living environments. A balance between energy efficiency and occupants' needs is required. This paper aims at providing insight on the concept of "Smart Home" considering the adaptive actions performed by occupants to restore their wellbeing.

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Keywords: Smart buildings; occupants behaviour; comfort perception; persuasive technology; energy engagements

1. Introduction

In recent years, the main goal of energy efficiency policies has been to promote the use of more efficient appliances and components. Building automation controls play an important role for the efficient and sustainable operation of the building. The building sustainable performance depends on the building structure, the building technical systems and the building users. Smart Home and building control systems have an impact on each one of them. The role of a building automation is especially important in operations aiming for sustained indoor comfort with energy-efficient control of building systems: (i) by identifying and eliminating energy waste (ii) by using energy only in the amount, at the place and at the time it is needed (iii) by implementing the right control

function level for the right application at the right place. Effective control of the heating, ventilating and air conditioning systems in a building is essential to provide a productive, healthy and safe working and living environment for the occupants. Along with good building design and efficient HVAC plant, the building control

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systems plays a vital role in the prevention of energy waste and reducing the environmental impact of the building. In the residential sector building automation is often referred to "Smart Home System". In the definition of Cook [1] the idea of a Smart Home "*is that computer software playing the role of an intelligent agent perceives the state of the physical environment and residents using sensors and then takes actions to achieve specified goals, such as maximizing comfort of the residents, minimizing the consumption of resources, and maintaining the health and safety of the home and residents*". In the following the concept behind a Smart Home System is explained..

1.1. Smart Home System

Several definitions of Smart Homes highlight that its concept is to connect sensors, appliances and devices through a communications network, in order to remotely monitor, access or control the residential environment [2,3,4,5,6,7,8]. Moreover, a crucial point of the Smart Home system is to provide services that respond to the needs of the users. Only in recent time, the term "Smart" or "Intelligent" is related to energy efficiency in buildings. Thus, it is often referred to provide a home energy management system (HEMS) managing energy consumption within homes [6]. In particular, these systems aim at maximizing electricity efficiency within homes and optimally controlling home equipment to reduce and optimize energy use, as well as create and store energy.

Actually the most important technology in the Smart Home system is the network itself (Figure 1) [8], that allows the real-time exchange of information from and to the buildings and users by connecting and coordinating all the technological devices installed in the system. Actually, it is the existence of this home devices connection that distinguishes the Smart Home System from a home merely equipped with standalone, highly advanced technological features.

While it may be self-evident that modern, highly serviced buildings require a advanced control system, it should be realised that simpler buildings relying on a heating boiler and natural ventilation can still benefit from a modern Home Energy Management System. The increasing emphasis on energy savings and reduction of greenhouse gas emissions serves to increase the importance of efficient controls. However, this approach is not the only way to reduce consumption. A better, more efficient use of traditional appliances and components can be equally effective. Therefore, along with promoting energy efficient equipment, energy efficiency policymakers are advancing another way to reduce consumption, thus improving system efficiency. In fact, increasing system efficiency is the only approach available to the many existing buildings that for cultural and historical reasons cannot be retrofitted to modern construction technologies. Improving system efficiency requires a central, centred control of all energy related components to insure that the whole system can work with highest efficiency. Moreover, the communication network is crucial in order to collect data from all the components of Smart Home and elaborate them to individuate appropriate strategies to increase energy savings. Efficiency is also affected by the capability of the system to communicate users their energy usage and change their habits, so the way communication is used to inform them (through ICT or other methods) is fundamental. Continuous monitoring of HVAC components is clearly considered to be helpful in reducing overall energy consumption in buildings. Significant electrical savings, ranging from 5% to 15% on average, can be achieved by understanding the details of energy usage at the level of individual devices within buildings [9,10] by providing users' information regarding the connection between energy and performed actions on devices.

The main services provided by Smart Homes are listed as follows and represented in Figure 2:

- Detect health conditions: i) eldercare ii) healthcare (only for sick people) iii) childcare (Safety)
- Store and retrieve multimedia from smart home (Entertaiment)
- Surveillance (Security)
- Devices monitor and control (Energy efficiency)

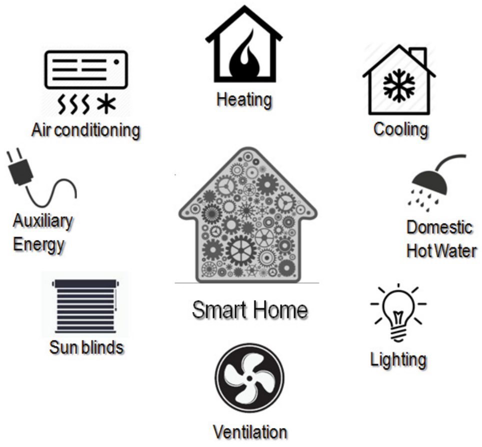

Fig. 1. Smart Home Network example

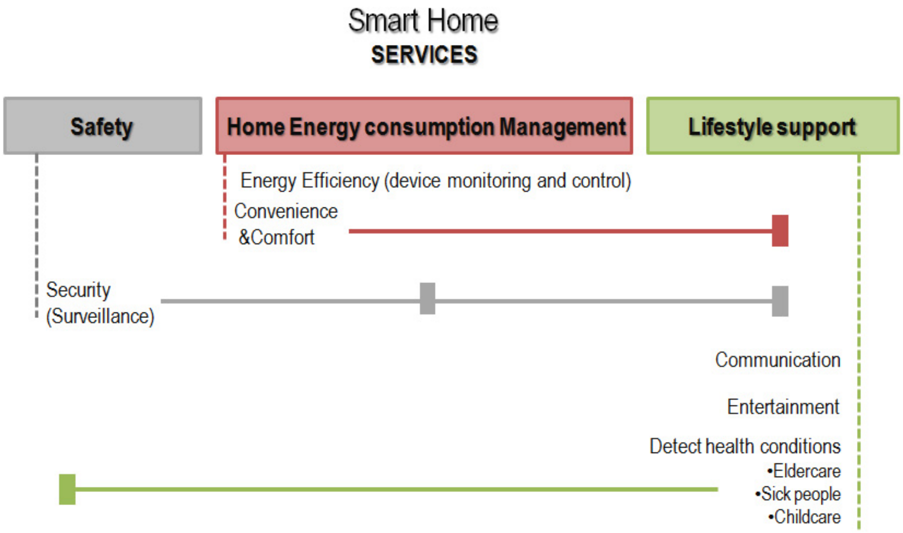

Fig. 2. Smart Home Services

Smart Home Systems offer benefits in many areas including limiting environmental impact, saving on energy costs and improving building security and safety. The systems not only regulate building functions, they transform data to help users determine ways to further decrease costs and increase the efficiency and comfort of their buildings.

Smart Home Systems should not only inform users about their environment, but also provide a degree of control over it where appropriate. Smart controls enable building occupants to modulate their energy use.

Energy in the form of heating, cooling, conditioned air and lighting should only be provided when there is a demand on the user side. Users should regulate when and how much energy must be consumed.

After finalising construction or renovation, the behaviour is adjusted to achieve the expected end functions of buildings, e.g. turning on the heating/thermostat when cold, opening the windows for ventilation, turning on the air-conditioning if too warm, switching on the lights, etc. Occupants' behaviour leads to wide discrepancy gap between the calculated final energy demand (i.e. the building envelope and the installations) and the real measured final energy demand. A solution might be self-learning automation systems adjusting the control algorithm according to the preferred settings of the occupants. Information and feedbacks to the building occupants should be considered when taking into account a "Smart Home"; in this sense in the last years there is a growing interest on the field of real-time feedbacks in both residential and office buildings. A recurring finding in the literature and its increasing application in smart buildings is the real-time feedback to inform occupants about their environmental conditions and energy usage. Researchers showed that rapid feedback to inform occupants are improving comfort conditions, but a correct system functioning is crucial for perceived comfort and satisfaction with systems [11,12]. The intuitive and immediate nature of operable windows to improve comfort results in a considerably wider range of acceptable conditions than in air-conditioned buildings [13]. Leaman and Bordass (2001) [14] found that quick responding building operators are also important to perceived comfort. Feedback to occupants to confirm that a system is functioning is particularly crucial for thermal systems, which normally experience a lag between control input and a change in the indoor environment [15]. The way how information are communicated to users is fundamental in order to make them aware and introduce changes in their energy-related behaviour. In particular, there are two questions to be taken into account. First, the instrument used to acquire and transfer the information. Second, how the information is expressed in order to be understood by users.

1.2. Persuasive Technology

Collecting information about any technical system, gathering consumption data through integrated meters including alarming and notifications about odd situations to the operational management are "commodities" for Smart Home Systems.

The Smart Home System provides information using metering and sensors, along with information on buildings assets and activities, such that benchmarks, powerful in diagnostic work, can be derived from that data - and produced for individual building configurations and activities supported.

The system allows continuous, automated evaluation of key performance indicators (KPIs) which prove that the building systems are controlled at their most sustainable energy-efficient level while maintaining indoor comfort closely related to building occupants' satisfaction, health and productivity.

Increasingly sophisticated techniques for monitoring their condition and performance, which facilitate failure prediction and performance/condition-based maintenance result in reduced cost of operation and maintenance and increased equipment life. KPIs could be used to detect any deficiencies in the control of energy-consuming technical equipment in the building.

The process provides a strategic approach for incorporating and delivering all the human interface/operation considerations and enables buildings to deliver what is required of them in the most cost-effective and sustainable way without compromising quality. Persuasive Technology [16,17] is a recent proposal for inducing changes in human behaviour through technology. The core idea aims to alter the mind sets, attitudes, and behaviours of users via technology–user interaction, program design, and data analysis. The discipline of persuasive computing falls under the scope of both computer technologies (internet, computer games, and so on) and psychological persuasion (change of motive, attitude, and behaviours). Persuasive computing has a rather extensive application range, including influence in the moral realm [18], the cultivation of sporting habits [19], as well as personal health [20,21].

Current electricity consumption feedback models only convey the monitored information in data records and statistical charts. In order to enhance the transmission strength of the information feedback for a better effect on energy conservation behaviour, several studies developed a persuasive feedback models that would emphasize and enhance the visualization of feedback information, the strength of user interaction, and the subconscious persuasion of users. These studies expected that users could be persuaded into practicing behaviour that would reduce electricity consumption, if sufficiently effective persuasion could be applied. Thus, the process of persuasion was derived from the characteristics and tendencies of the user.

According to Fogg [17,22], persuasive technology is broadly defined as a technology that is designed to change attitudes or behaviours of the users through persuasion and social influence. A feedback is defined as information regarding the result of a process or action that can be used to modify or control another process or system, especially by noting the difference between the desired and the actual results [23,24]. There have been various studies on feedback in energy conservation and general behaviours in different fields, such as psychology, human computer interactions and engineering technology [25]. Therefore, feedback has a significant part to play in bringing about energy awareness, conservation and motivations needed across various residential settings, especially in student halls [26]. Therefore, the persuasive technology is the concept, dedicated real time feedback interface and energy delegate are used in the implementation and sustainability of this concept to form a persuasive system.

Feedback can be described as “the mechanism that directs attention to a specific goal” [27]. The most common form of feedback informs participants about their own energy usage, often drawing comparisons to the past. Because most individuals have low awareness about their energy usage or its impacts, periodical energy use reminders, may render energy usage more salient and help trigger conservation activities. In addition, learning about one's own electricity use may increase the sense of relevance of taking action to conserve. If individuals perceive their own impact as negligible, they might not behave in a pro-social manner. Consequently, making an individual more aware of their own energy usage may contribute to conservation.

2. Interactions of occupants with building control

As already partially explained, the contribute of users in energy conservation is crucial. In particular, users' satisfaction in terms of indoor comfort could allow to save energy. Energy saving could be achieved by automatically switching on or off lights when people are not present in the room/building, or by dimming the artificial lights in case the quantity of daylight available is enough to perform the required visual task. An important warning regards the fact that such “smart behaviour” of the building should match with the occupants’ satisfaction and his/her control feeling of their living environments. In fact, if the actions of the building automation system is based only on energy-saving requirements, the resulting indoor environmental conditions could not be perceived as “comfortable” by the occupants. Thus, a balance between energy efficiency and occupants’ needs and perception of comfort is required. Moreover, human behavior at home is highly unstructured. Multiple sensory modalities are required to sense such behavior. Advance pattern recognition techniques are required to recognize the behaviour of multiple residents.

Actually, the main aim of a building automation system for energy and comfort is to match comfort requirements by reaching high comfort indexes (for hygro-thermal, visual, air quality, but also with plug loads usage).

Many aspects have been recognized in literature as having an impact on the occupants’ comfort perceptions. They include as aforementioned environmental factors (e.g. climate), social factors (e.g. open-plan office or single office) or physiological factors (e.g. gender, age). Another important factor influencing occupants’ satisfaction is the feeling of control in the living spaces. Sociologists and psychologists have highlighted that the perception of control is a robust predictor of comfort and wellbeing both physical and psychological. For example in office environment, sharing offices causes a dissipation of reliability, by means of which office occupants assume that actions like switch off the lights at the end of the day is performed by colleagues. Comparatively, a smart building with automated systems causes an analogue consequence, since users do not feel they do not represent a significant actor in maintaining/improving the comfort conditions.

The feeling of control, moreover, is often taken into account in technology acceptance models and occupants’ satisfaction benchmarks [28]. Veitch [28] identified this “perceived control” as a fundamental psychological means having a significant impact on satisfaction with lighting quality and above all with the working environment. She reported that people with a possibility to dim lights confirmed higher ratings of satisfaction with surrounding environment, lighting quality but also with self-rated productivity. Moreover, they described more motivation and improved attention achievement. In a similar way, Newsham [29] reported an experimental study in a laboratory. This investigation confirmed that a lighting system provided by a dimming control is a reason of enhancement of mood, satisfaction with the environment, and self-assessed productivity.

Many researchers investigated primarily office buildings, since the strong relationship among the positive impact of personal control and the satisfaction from overall work environment. This feeling of control is defined as “individuals with control can act to change or reverse situations which are disliked”.[30] Technology acceptance and users' perception of Smart Homes' benefits are fundamental for their implementation. In fact, customers should be able to understand Smart Home peculiarities in order to overcome some typical social barriers and change their attitudes for willingness to pay.

3. Smart Home drivers and social barriers

Willingness to pay is driven by i) expected savings ii) perceived usefulness of consumption feedbacks iii) environmental awareness iv) intention to change user behaviour v) trusting data protection (privacy issues).

Major barriers to home automation are listed as follows:

- losing control
- reliability
- viewing smart home technology as exclusive or irrelevant
- high installation costs

End-users' needs should be taken into account when designing and implementing a smart home, because they determinate the value of offered services. About a half of consumers who currently do not receive any specific products or services from their electricity provider would be interested in installation and/or maintenance services for home energy management, but although consumers may be interested in smart homes, current market prices will turn of them away.

Moreover, beside smart thermostats, consumers have shown strong preferences for real-time monitoring of household appliance energy consumption. Several pilot projects [31] have revealed that significant energy savings can be expected when consumers are able to monitor their energy consumption in real time.

The ecological implication of smart metering, smart devices, and finally the smart home is mostly seen only as a positive side effect within a larger package; it remains unclear whether this will stand alone as a genuine driving factor in purchasing decisions.

The main concern on Smart Homes by users is related to invasion of the domestic privacy and too much intrusive technologies. On the other hand, energy efficiency issue is a major driver for choosing a smart home system since energy cost is high and people are more triggered to buy system allowing them to consume less energy. In this framework, the main market challenges for the development of Smart Homes are represented by

- Retrofitting of existing homes. People prefer to adapt their homes into a smart environment instead of buying a new home.
- Interoperability. Adoption of universal standards for communication protocols.
- Reliability. People trust on technology services. In particular, smart home managing platform is crucial because only when standards are set systems can be reliably integrated.
- Privacy and security. In a network system people are worried about their home security and privacy.
- Costs. The perception is that these systems are “High class society technologies”. Moreover, users are worried by high costs of demand-response appliances as well.
- Usability. Complex systems are often related to difficult user interfaces. Usability is then a crucial aspect for the technology to be used.
- Governement role. According to Ehrenhard M. et al [32], governement's role should be not underestimated. In fact, it could help regulating the market, enforcing standards, safeguarding privacy and change funding schemes in order to influence smart home's market development.

4. Smart Home in a smart grid.

Another fundamental aspect on Smart Home implementation path regards the possibility to profit of the creation of a network within a group of them. In particular, the creation of a Smart Grid could allow different users to profit of a larger network of energy production and manage their energy demand, with a great possibility of energy-related costs reduction.

The overall electricity market in the EU is transitioning from a centralized, fossil fuel, national system towards a more decentralized, renewable, interconnected and variable system, where buildings could become active players.

Enabled by technology and business-model innovation, buildings will become active players in the energy system. As opposed to only using energy from the grid, they produce, store and supply energy or help balance the grid with demand management. This role of demand response and flexibility management will ask for the integration of automated steering systems and storage units at the building level. The uptake of demand response and power storage is coherent with the uptake of related technologies, such as energy management systems, smart meters, smart thermostats, heat pumps and electric vehicles. The integration of electric vehicles in the energy cycle of buildings is advantageous for the energy use of a building and its energy flexibility in the grid.

Another important goal is to minimize the energy demand. Energy prices in the future will depend strongly on availability of energy. Communication and information-exchange with the rest of the grid will be crucial. Automation is capable of monitoring continuously all demands as well as the exact supply of renewable energy. Shifting demand is a general strategy for optimizing renewable energy. The required balance between minimized energy losses, internal gains and the remaining energy need requires for nearly zero energy buildings a well mastered equilibrium. Building automation will play a key role for the successful implementation of nearly zero energy buildings. Building automation is needed as the connector of all the single requirements for nearly zero energy buildings, such as a well-insulated and airtight building shell, efficient HVAC system and a high share of renewable energy.

Building automation is needed to reduce the primary energy consumption, especially by automatic optimization functions, to increase the amount of (directly usable) renewable energy, on- and offsite and to monitor the success of the building concept in real operation. Therefore, it is clear that nearly zero energy buildings require sophisticated central control systems, controlling all energy-related components simultaneously. An autonomous control, e.g. of the shading device without connection to the heating or illumination systems, causes wasted energy.

Most important – energy efficiency – functions are to drive generation, distribution and emission of energy in systems so, that the performance gets maximized. Together with the traditional energy supply contracts (e.g. utility or supplier of district heat) there is a need to control / manage the energy sources according to their availability.

This means that the automation system might need to predict local renewable energy production, weather conditions, storage charge situations and even predicted use of the building space in order to maximize effects supporting the targets.

Additionally, the integration of the significant share of renewable energy which is required for nearly zero energy buildings makes it important to manage the interaction of the produced energy with the buildings own consumption and the needs of the electricity grid.

Consequently, the realization of nearly zero energy buildings will require building automation systems not for many but probably for all new non-residential buildings with these systems needing to be capable of and fine tuned to the specific needs of such buildings. Thus, more advanced Home Energy Management Systems (HEMS) will play an important role for the realization of well performing nearly zero energy buildings.

The main benefits are listed as follows:

- Minimizes energy demand and energy costs
- Risk management and energy security
- Energy flexibility
- Supports net-zero building operation

In Figure 3 is represented the Smart Grid infrastructure highlighting the role of aggregators in demand response scenarios. Aggregating demand response, storage and on-site power production, as well as monitoring and controlling them saves money for building owners or occupants. According to HVAC manufacturers, it appears that the main advantages for monitoring the in-use energy consumption of their products would be the additional value for the customer and the ability to comply with forthcoming legislation aimed at nearly Zero Energy Buildings.

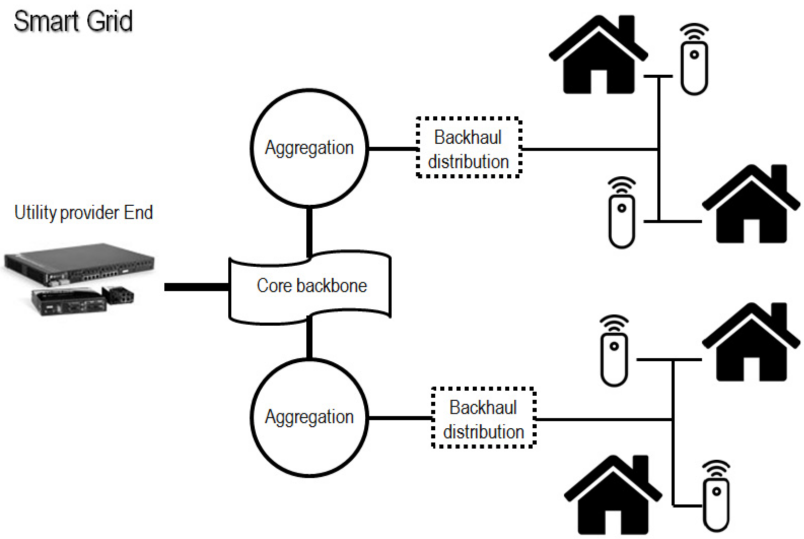

Fig. 3. Smart Grid Infrastructure

5. Discussion

In the context highlighted in this paper, a Smart Home refers to a concept of energy usage and management in buildings that include not only efficient demand sequenced controls but takes into account:

- Supports all energy efficiency functions according to EN 15232. Integrated building automation and control system integrated for multi-disciplinary relationships between various building services and technologies;
- Support peak demand limiting algorithm. Demand response requires a deep knowledge on advanced metering, and dynamic pricing. This technical competence has to be complementary to an effective communication program to measure and verify the performance of demand response providers and of building energy performance in one hand, and on the other hand the engagement of occupants' awareness and education about the benefits of demand response;
- Locally or nearby generated renewable energy controls integration. The contribution of households' energy demand and production patterns (prosumers) of the energy system (demand response technologies) should also be developed. The rise in energy production efficiency may be obtained by means energy peak shifting, load prediction, onsite electricity production (photovoltaic panels) and onsite energy storage (storage battery).
- May include managing energy usage according to committed demand curve. Increasing the use of energy management technologies at building level (residential and commercial) as well as the market deployment of real time optimization of energy demand and supply intelligent energy management systems, reducing the difference between peak power demand and minimum night time demand, by means onsite energy storage strategies. The impacts of such investments can be measured in energy/cost savings and for the willingness/capability of consumers to response replicable solutions.
- May allow optimal managing different target KPI's (e.g. total consumed energy, CO2 footprint mineralization, total minimal cost). Persuasive communication technologies are a useful tool to engage people and educating them to energy savings and habits changing.To meet the comfort or special process requirements at various climatic conditions building automation controls the amount of heating, cooling by using different control strategies to meet fixed or variable setpoints for temperature, humidity, air quality, etc. Limiting heating or cooling periods and climate conditions to actual needs leads to significant reductions in energy requirements in the residential sector as well as the tertiary sector. The most important automation functions useful in reducing

consumption related to temperature control include the establishment of micro-zones. Instead of central or no temperature control, micro-zones with independent thermostats and valves optimize both comfort and energy consumption.

Integrating temperature control with a weather station that monitors rain, wind, and brightness can allow automatic deployment of awnings, blinds, outdoor lighting mitigate energy losses. Also the occupancy-based climate control allows the automatic adjustment of indoor climate conditions according to occupancy or time of day and upon the opening and closing of doors or windows. Regarding the Indoor air quality (IAQ) control, rather than running the air exchange system periodically, a sensor analyses the pollutants concentrations in air and activates the air exchange system only when needed.

Automated controls that limit the operation and intensity of artificial lighting can have a significant impact on electricity consumption, particularly in the service sector. Sensors that detect ambient light levels, occupancy/vacancy, or motion can be programmed to application-specific set points to actuate a wide range of functions. The allowance for manual switching is a crucial aspect in a Smart Home. It allows for local or centralized changes from automatic to manual switching between different comfort modes. For example, motorized shutter and awning operation can be either timed or associated with specific scenarios. All can be operated by remote controls, light sensors, or weather stations. Literature agreed on a rapid growth of smart home by 2020. Actually, there are specific housing stock characteristics having an impact on smart home diffusion. In particular, the physical outline and size of buildings influence daily activities, routines and system types' choices. The strength and coverage of communication signals could influence operations inside the building. Signals' propagation could be affected also by other physical characteristics of the building, such as materials, insulation, height and building type (single family or flat). In addition, building's ownership (rental or own) affects choices in installation and use of technologies and appliances. Eventually, also the age of residential building stock could influence type and relevance of interventions, for instance, owing to preservation instances [2]. In addition, considering systems' technologies and their building implementation, a list of pros and cons could be elaborated as showed in the table below.

Table 1. Comparison between Home Automation and Traditional Systems through pros and cons.

Home Automation Versus Traditional Systems		
	Pros	Cons
Home Automation	-System's flexibility -Each appliance could have more functions -Easier wiring -Control systems are safer	-More expensive systems -Technology not well known by most technicians
Traditional Systems	-Less expensive -Technology known by all technicians	-Scarce flexibility due to physical connections -Superior number of appliances

6. Conclusion

For more than a decade, the Smart Home has promised to offer a better quality of life by connecting in-house devices and monitoring their usage. Such platform-based configuration technology has demonstrated the potential to improve comfort, healthcare, safety and security, and energy conservation — both at home and in the office. Moreover, since these technologies foster users' independence, Smart Homes can be both an answer to an aging workforce and a large market for an aging customer base.

In recent days we can find there are a growing number of new research proposals and findings in related to new and alternative energy technologies. However there are many easy and cheap ways to reduce energy use at our homes by efficient energy management. Most of these simply require a change in behaviour of the occupants of the home.

Users' usage of energy in a smart home is driven mostly by:

- comfort
- convenience

- financial savings
- system's costs
- emissions reductions

Autonomous monitoring and control in a home environment can lead to energy savings. Also autonomous monitoring can serve as an alerting mechanism when something is out of the norm so that the controlling mechanism can rectify the problem.

In the future, smart meters and HEMS will play a role in providing electricity usage data, which will result in the emergence of various new services.

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