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RESEARCH and EXPERIMENTATION

Experimental demonstration of a smart homes network in Rome

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ABSTRACT

According to the European Strategy Energy Technology (SET) Plan, the resident-user engagement into the national energy strategy is pivotal to the project as it is considered to be one of the most important challenges. The Italian Minister of Economic Development and ENEA has entered into a Programme Agreement for the execution of the research and development lines of General Interest for the National Electricity System. In particular, as part of the "Development of an integrated model of the Urban Smart District" a Smart Home network experimentation has been carried out in Centocelle, in the south-eastern outskirt of Rome.

This project aims to develop a replicable model able to monitor energy consumption, indoor comfort degree and safety in residential buildings. Then raw data are transmitted to a higher level ICT platform where they are analysed and aggregated to provide the user and the community with a series of constructive and valuable feedback. All this information can shed light on the user's behaviour patterns and what ought to be improved to increase their energy awareness. The heart of the system is the Energy Box (EB) that allows to control all the devices (sensors and actuators) and to transform each and every home into an active node of a smart network. It lets the user share data and information with the outside world as well as to increase residents' sense of involvement and belonging to the community, providing them with new forms of interaction. In perspective, the system architecture aims to transform each user from a mere consumer into an active participant in the energy market, able to control demand (demand-side management). Finally, the brand-new home digital infrastructure is paving the way to a series of additional services, such as assisted living and home security.

Keywords:

Smart home;
Users' energy awareness and feedback;
Energy aggregator;
Smart services;
Wireless sensors;

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1. Introduction

Growing awareness of the world's energy scarcity and environmental issues has introduced new conditions within the energy system. An emblematic example is an electrical system, which, in the future, will have to accommodate a share of production much greater than today. This issue poses new challenges to the power generation system and end-user energy consumption behaviour. The current trend points to the direction of changing the network to manage future challenges, such as energy storage availability and flexibility, and as well as improving the balance between energy production and consumption. Also it is thought to support the transition towards Zero Energy Emission Districts (ZEED) in the near future [1]. As a result of this development, a large number of programmes have been implemented in Europe and the World over. The first generation of these projects was focused on technology and electrical grids, while social and behavioural issues were overruled or not sufficiently detailed. In recent years, as several case studies have shown, behavioural supporting measures

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The added value of the "Experimental demonstration of a Smart Home network in Rome" for ARETI is the first, needful and concrete step toward the inclusion of end-users into the optimised management of the grid, with the scope to foster decarbonisation and avoiding an unnecessary investment on wiring as much as possible. This goal is reached by increasing the capability of the actual network to transfer energy to end-user by harmonising and balancing the customer's load throughout the day: this can be only achieved having, simultaneously, DSOs equipping their network with proper "flexibility management systems" and Customers adopting "Smart Home" philosophy/technology.

Ercole De Luca, Innovation – Grid Flexibility & Dispatching, Areti

proved valuable to make users feel more involved in the project and help them gain an advantage in terms of energy savings.

For this purpose, in December 2015 the public consultation process was dedicated to the 2nd Energy Union Research, Innovation and Competitiveness common priority, for "facilitating the participation of consumers in the energy transition through smart grids, smart home appliances, smart cities, and home automation systems" [2].

This paper aims to describe ENEA Smart Home Model developed to increase awareness on energy-saving issues throughout the adoption of IoT technologies. Not only do smart technologies help people save energy, but they can also improve comfort and convenience at home by offering innovative services. It examines the experimentation of a smart home network, describing the technological solution and giving a brief outline of the methodology. Drawing from available studies, we estimate household energy savings relative to average energy consumption for each household. Additional research will improve these estimates in the next years. Furthermore, the experimentation was evaluated in terms of people's satisfaction with the technology in use from a social and psychological point of view.

2. System technological infrastructure

Prior to the start of the experimentation, a study was conducted on the state of the art in order to define the necessary requirements and identify the best technological solutions. The SNH system design is based on those requirements that the identified technological solutions are able to supply, i.e. the use of standard and open communication protocols or the adoption of wireless devices, easy to install and quite inexpensive [3][4][5]. In collaboration with Apio company, ENEA has designed a Smart Home System and Aggregation platform [5] to provide guidelines for more efficient and energy-aware behaviour. SHN enables the exchange process between homes and the Aggregator to manage user flexibility and benchmarking.

Nowadays, Smart Home market and particularly IoT is constantly growing (185 million Euros, + 23% compared to 2015) [6] but, until now, it has been mainly driven by security issues, despite technology rapid progress promises to make more features available in the near future [7].

Smart homes use technologies like smart thermostats, appliances, and lighting to enhance residents' comfort and convenience in their homes. These technologies connect to one another through home wireless networks and to the larger world through the Internet. Using software, sensors, and other hardware, they monitor and control the home's systems and allow residents to access them when they are away. The heart of the system is the Energy Box (EB) that continuously collects data on energy performance. It can communicate wirelessly with other devices installed at home through standard and open communication protocols and acts as a gateway for the information transfer to the external I-cloud via WiFi and/or Ethernet. The connection architecture is described in the following figure.

The smart toolkit is made up of sensors that adopt a single communication protocol, Z-Wave, for monitoring electricity consumption and indoor comfort. They can also control some thermal and electrical utilities. In particular, the following devices have been installed as shown in figure 2:

- Electric Smart Meter, installed in the apartment electrical panel underneath the general switch for monitoring the overall apartment electricity consumption;
- Smart Switch for monitoring consumption and controlling air conditioners;
- Smart Plug for monitoring and controlling several electrical devices (e.g. appliances);

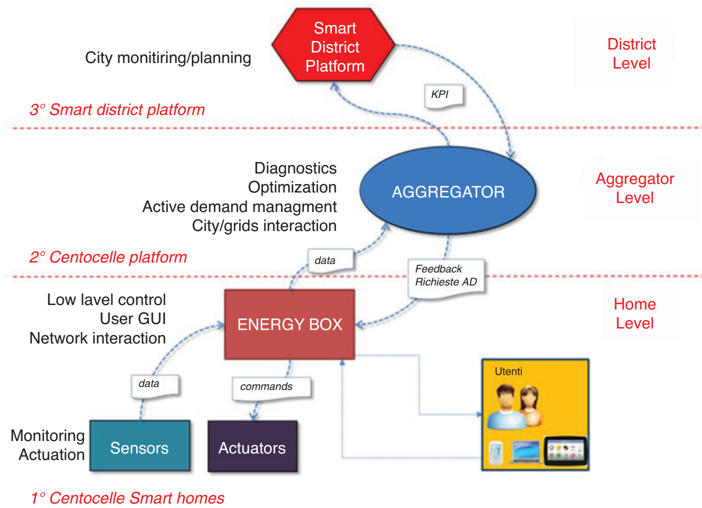


Figure 1: Connection architecture

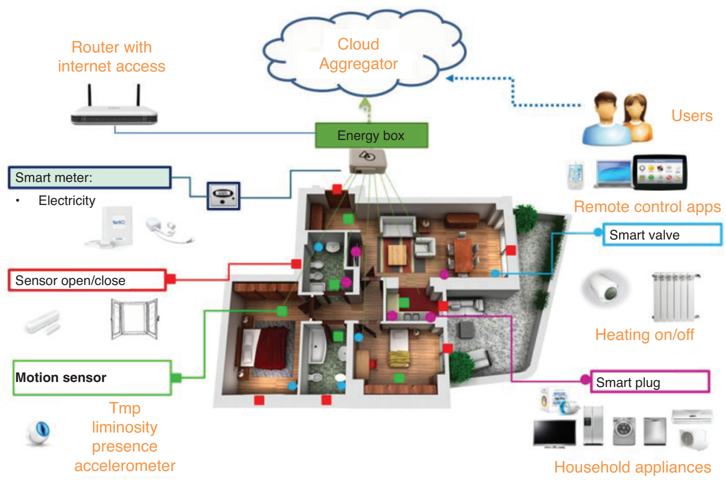


Figure 2: Smart home toolkit

- Opening and closing sensors on doors and windows;
- Integrated comfort/presence sensors for monitoring indoor temperature, brightness and user presences.
- Smart valve for monitoring and controlling the radiator set point.

Each device matches a web-APP, accessible from a computer or mobile phone, for real-time display of sensors' acquired data. The web-app controls the actuators, such as the smart plug and smart valve.

3. Data Collection and Analyses

This project aims to develop a system of SHN able to monitor energy consumption, the degree of comfort and safety in residential buildings. All acquired data are then transmitted to a higher level platform where they are stored, analysed and aggregated. In coming years, efforts in data analytics to disaggregate smart technology–generated data into meaningful, actionable findings will be also quite useful to streamline data processing. The goal is to reduce the final domestic energy consumption leading users through a path of growth of energy awareness as well as offering additional services. In addition, the Smart Home infrastructure can enable the home user to demand response services. In perspective, users can modify their energy demand in response to requests from an Aggregator, receiving a reduction of the energy cost in return.

a. Energy Feedback

A dashboard was designed to provide users with valuable feedback [9]. It guides users towards more energy-efficient behaviour to help them better understand how much energy they are using in their daily activities. As users become more aware of their energy consumption they can change their energy-related behaviour as well as shift their operation to off-peak hours when, for instance, there is higher availability of energy from renewable sources. As a result, residents who use feedback from these devices can further adjust their energy use, reducing their energy footprint. In fact, providing the user with information about their past and present energy consumption has the ambition of modify their behaviour. To support users during the process, technical vocabulary has been translated into terms easier to understand, such as cost or bill. Finally, a web-app was developed to give users real-time feedback and an overview of their energy consumptions [8].

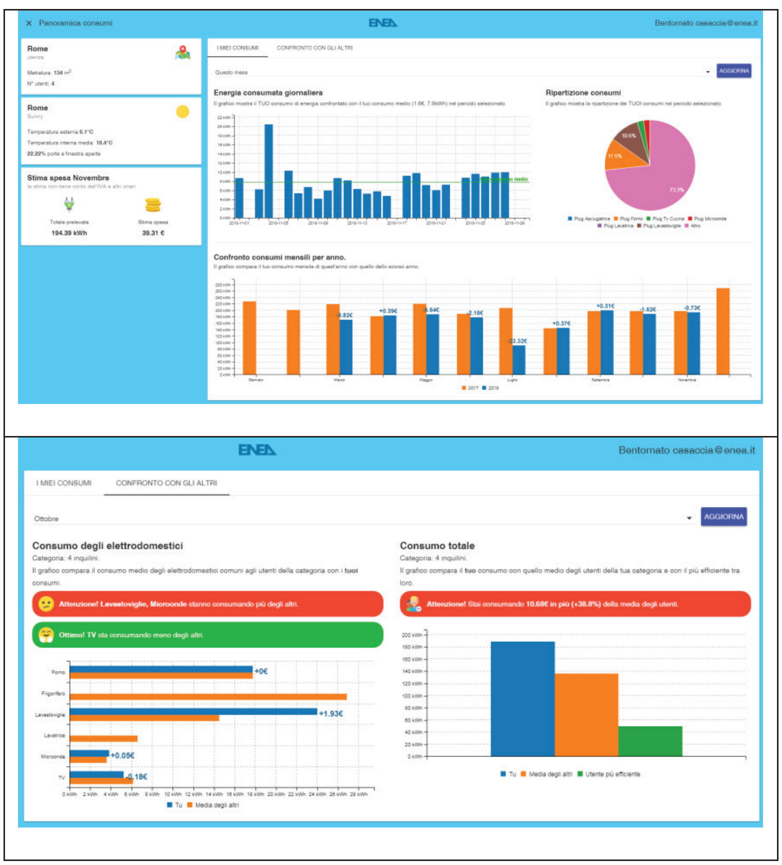
The following set of information is provided within the App:

- Generic information: map position, house size and family unit composition;
- Weather conditions, external temperature compared with the average internal temperature, window opening percentage;
- Estimated monthly electricity consumption for the date of access to the App in both kWh and €.

Each and every user may choose whether to compare their results with themselves or other participants. In the dashboard section called "My consumption", for the chosen reference time interval, you can view:

- Daily energy consumption: using a bar chart showing the consumption in kWh and the costs in €, and comparing them with the average value, as to easily identify in which day or hour the higher consumption was recorded. It shows the user when and where their consumption is.
- Distribution of consumption among monitored household appliances. In this way, it is feasible to identify for which users the highest consumption is recorded and the respective incidences on the bill costs.
- Comparison of monthly consumption for the current year with the previous one. The comparison makes it possible to monitor whether there has been an improvement in the user's behaviour or if there are savings compared to the previous year when no control system was going on.

Table 1: User interface: My progress - Comparison with others



- In the section called "With others", the consumptions of the selected time interval are compared with families similar by composition. In this case, the provided set of information is:
    - Comparison with the average and the most efficient among similar users: the comparison is carried out in percentage. A comment follows that can be "Attention" you are consuming more than the average of similar users or, "Congratulations" if the consumption is lower.
    - Comparison between the consumption of household appliances of the single user with the users' average consumption of the same category.

b. Additional services

From the very beginning home users were offered a bunch of additional services. Thanks to local processing capabilities, it looks feasible to manage situations of potential risk [9]. Incorporating heterogeneous data is vital to decision support, with a consequent reduction in costs and user satisfaction.

The additional services offered are described below:

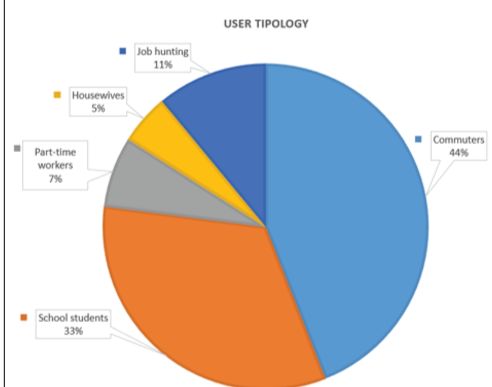
- Security – services which provide, when an end-user is away, home detection or the break-in of the locking systems. The system is able to provide a warning notification to the end-user or third party specifically enabled;
- Safety – services which monitor specific environmental parameters (smoke detectors, CO_2, flood sensors, etc.) and to detect particular risk situations to prevent injuries and disasters;
- Assisted living - services to support vulnerability and to improve quality of life.

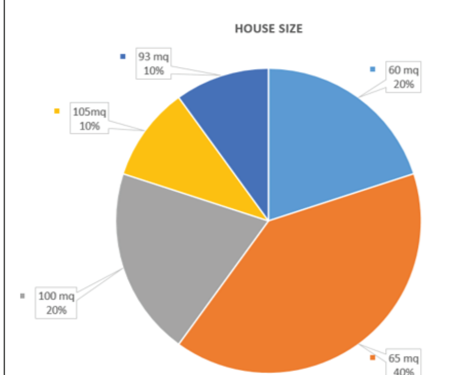
4. Experimental demonstration

Beginning in May 2018, pilot testing [10] of the Smart Homes network was started in Centocelle, a suburb in the south-eastern district of Rome [11]. During the recruitment phase, to reach out to a wider range of neighborhood inhabitants, a series of meetings were organized with active social groups. In addition, various multimedia tools were used to convey the project [12]. The table 2 below describes the characteristics of the apartments and users' profile.

Table 2.Building typology and users' profile

PICTURE	ID	BUILDING TYPE	m^2	YEAR OF CONSTRUCTION	N. OF FAMILY COMPONENTS
	C1	Flat in multi-family apartment block	49	1919-45	
	C2	Flat in a two-family house	101	1919-45	
	C3	Flat in multi-family apartment block	100	1962-71	
	C4	Flat in a two-family house	50	1946-61	
	C5	Flat in multi-family apartment block	100	1946-61	
	C6	Detached house	65	2010-15	
	C7	Flat in multi-family apartment block	65	1991-05	
	C8	Flat in multi-family apartment block	60	1962-71	
	C9	Flat in multi-family apartment block	95	1946-61	
	C10	Flat in multi-family apartment block	102	1962-71	



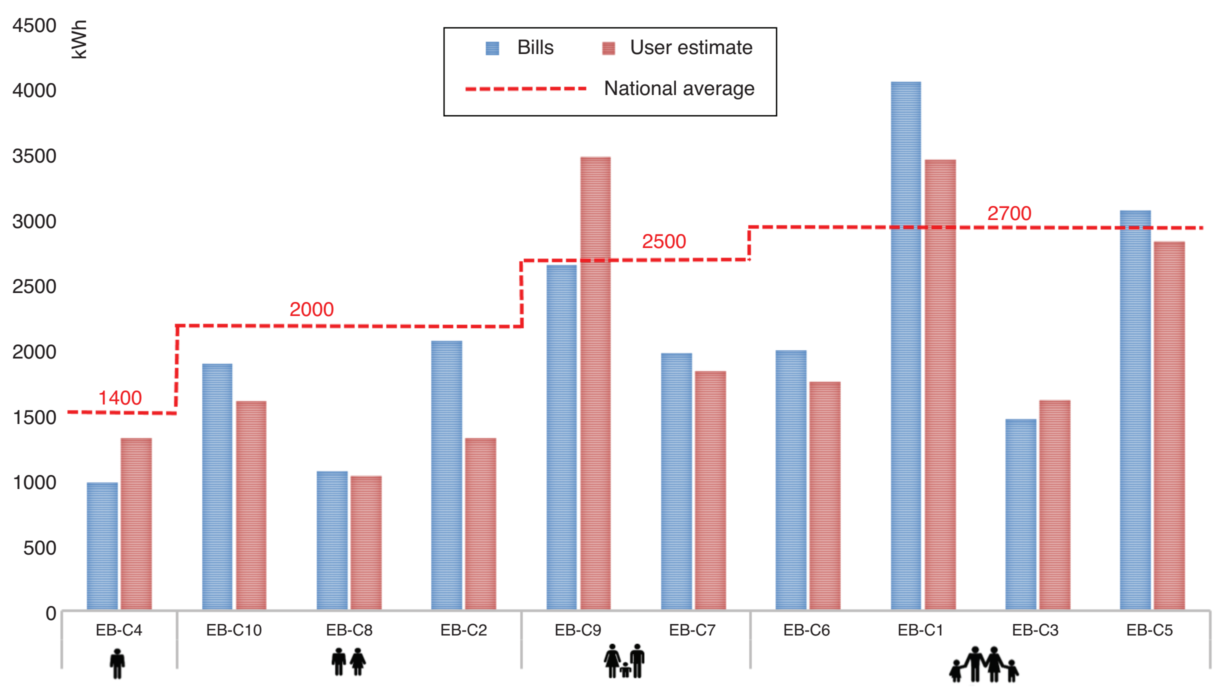


During the trial period, 10 families spontaneously joined the project. At first, participants were given a questionnaire on the basis of which simulations were carried out. Results made it possible to estimate home consumption [13][14], to profile the type of user and allow evaluation and benchmarking. Simply comparing the actual bill electricity consumption and the estimated consumption based on the information provided by participants, it was found that in most cases users consume more than it was expected, and this percentage was approximately 30%. This analysis, carried out even before the experiment started, confirmed the lack of awareness the majority of users involved in the trial project had. Furthermore, the 2017 electricity bills related data, based on real consumptions, were then compared with the typical electricity consumption available in Italy, issued by the Electricity and Gas Energy Agency (AEEG)[15] and by the Italian Institute of Statistics (ISTAT)[16]. The comparison was carried out among homogeneous groups, i.e. families similar in terms of the number of components. This process has helped identify the most energy-consuming users and those in need of efficiency improvements. However, findings suggest that families involved in this experimentation presented lower levels of energy consumption compared to the Italian average values, as shown in the following graph.

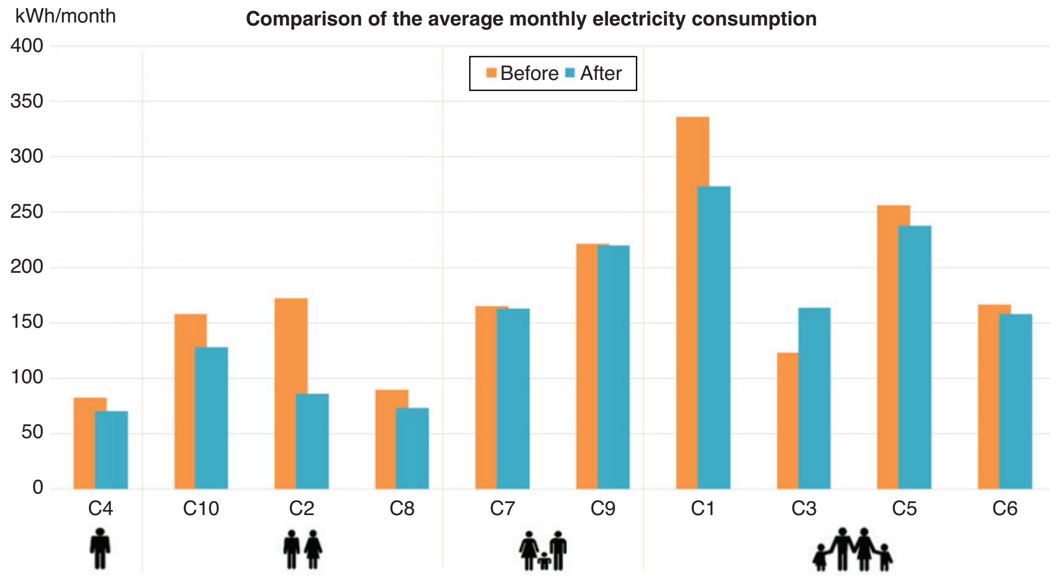
5. Results discussion

Data colleting method of electricity consumption made it feasible to verify the results of the experimentation in terms of families' savings on electricity bills. The following graph shows the average monthly consumption and the percentage of savings. Results suggest that the average savings were about 10% for each household, even though the greater incidence was found in single or two-component families, where the effects of the individual user lifestyle changes and habits are more evident.

Generally speaking, the results can be regarded as positive, especially considering that it is mainly due to a change in the users' behaviour, given that no automatic control was on, not to mention the real-time feedback and competition naturally spreading among users. Furthermore, we carried out a comprehensive survey of technology user-friendliness. For this purpose users were given a questionnaire with the result that the technology in use has gained a widespread acceptance, even if improvements have been requested especially in terms of product customisation. To realise the full potential of smart technologies, consumer acceptance must evolve beyond early adopters [17], and reach the broader population even if the survey showed that mounting cybersecurity threats and breaches were one of the most



Graph 1: Comparison of real annual electricity consumption estimated by the user compared to the national average by type of family



Graph 2: Comparison of the average monthly electricity consumption before and after the trial project

sensitive issues. Users have been reassured in this regard. Home data are acquired anonymously and are not sold to third parties, but exclusively used for benchmarking as well as the tracing of user energetic profile and behaviour was rendered unfeasible to one another.

5. Conclusion

The deployment progress has shown the possibility to actively engage home users. The average saving was approximately 10% on electricity consumption per household due to the technological solution in place. Several DSOs and electric utilities have currently shown interest in this experimentation as it allows the use of flexible resources that lie among residential users, while the technological solution has proved to enable the active involvement of the end-users in the advanced network management. In coming years, further step will have to be taken to build up strong foundations of a real energy community, integrating smart sensors and a brand-new type of energy meters with accounting and exchange certification systems. The aim is to maximise the use of renewable sources by exploiting storage and energy exchange within the same smart energy community [18]. Nevertheless, it should be considered that many smart home technologies are wireless, which means they need their energy requirements to support their sensing, communication and control capabilities always being in network standby mode. This could diminish any incremental energy savings and it should be taken into account when evaluating the energy performance of any smart technology system.

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References

[1] Pinna R, Costanzo E., Romano S., Parways to ZEED, TECHNE Special Issue 012018;1. http://www.fupress.com/techne DOI: 10.13128/Techne-22736

[2] https://setis.ec.europa.eu/implementing-integrated-set-plan/smart-solutions-consumers-ongoing-work

[3] S. Aman, Y. Simmhan, V. K. Prasanna, University of Southern California, "Energy Management Systems: State of the Art and Emerging Trends", rivista IEEE Communications Magazine – (s.l.) IEEE, January 2013 -1: vol 51, pp: 114–119

[4] L.Liu, Y. liu, L. Wang, A.Zomaya, S.Hu, "Economical and Balanced Energy Usage in the Smart Home Infrastructure: A Tutorial and New Results", IEEE Transactions on Emerging Topics in Computing (Volume:3, Issue: 4) pp: 556–570.

[5] https://www.smarthome.enea.it/

[6] Politecnico di Milano, "Internet of things: oltre gli oggetti, verso i servizi" : Milan, Italy, April 21, 2017. https://www.osservatori.net/it_it/catalogsearch/result/index/?format=102&q=internet+of+things%3A

[7] Energy Impacts of Smart Home Technologies Jen King April 2018 Report A1801 https://aceee.org/research-report/a1801

[8] Tiago Serrenho, Paolo Zangheri, Paolo Bertoldi " Energy Feedback Systems: Evaluation of Meta-studies on energy savings through feedback". https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/energy-feedback-systems-evaluation-meta-studies-energy-savings-through-feedback

[9] Taraglio S, Chiesa S, La Porta L, Pollino M, Verdecchia M, Tomassetti B, et al. DSS for smart urban management: resilience against natural phenomena and building heat dispersal assessment. Int J Sustain Energy Plan Manag 2019;24. http://doi.org/0.5278/ijsepm.3338

[10] S. Fumagalli, S. Pizzuti, S. Romano, "Smart Home Network: sviluppo dei servizi di aggregazione e progettazione di un dimostrativo pilota". Report RdS/PAR2016/006. http://www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/adp-mise-enea-2015-2017/smart-district-urbano/rds_par2016_006.pdf

[11] Cassinadri E, Gambarini E, Nocerino R, Scopelliti L. Sharing Cities: from vision to reality. A people, place and platform approach to implement Milan's Smart City strategy. Int J Sustain Energy Plan Manag 2019;24. http://doi.org/10.5278/ijsepm.3336

[12] Meloni C, Cappellaro F, Chiarini R, Snels C. Energy sustainability and social empowerment: the case of Centocelle smart community co-creation. Int J Sustain Energy Plan Manag 2019;24. http://doi.org/10.5278/ijsepm.3339

[13] L. de Santoli, F. Mancini, M. Cecconi, C.I.T.E.R.A - Centro di Ricerca Interdipartimentale Territorio Edilizia Restauro Ambiente Sapienza Università di Roma"Sviluppo di una procedura semplificata per la valutazione del potenziale di aggregabilità di utenze residenziali". Report RdS / PAR2016 / 009 http://www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/adp-mise-enea-2015-2017/smart-district-urbano/rds_par2016_009.pdf

[14] P. Cannavò, C. De Angelis, E. De Nictolis, C. Iaione, A. Noce, A. Palladino, S. Parlato, C. Prevete, C. Rocca, B. Sdao. Libera Università Internazionale degli Studi Sociali Guido Carli (LUISS),"La pratica e la prototipazione della co-governance per uno smart district urbano", Report RdS/PAR2016/026. http://www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/adp-mise-enea-2015-2017/smart-district-urbano/rds_par2016_026.pdf

[15] Agenzia per l'Energia Elettrica e Gas (AEEG). https://www.autorita.energia.it/it/index.htm

[16] Istituto Nazionale di Statistica, ISTAT. http://www.istat.it/it/

[17] Botticelli M, Dionisi, F. Monteriù A., Romano, S. , A Smart Home Network for Proactive Users. REAL CORP 2019 – IS THIS THE REAL WORLD? Perfect Smart Cities vs. Real Emotional Cities. Proceedings of 24th International Conference on Urban Planning, Regional Development and Information Society. pp. 55-62. ISSN 2521-3938

[18] Heinisch V, Göransson L, Odenberger M, Johannson F. A city optimisation model for investigating energy system flexibility. Int J Sustain Energy Plan Manag 2019;24. http://doi.org/10.5278/ijsepm.3328.

[19] Østergaard PA, Maestosi PC. Tools, technologies and systems integration for the Smart and Sustainable Cities to come. Int J Sustain Energy Plan Manag 2019;24. http://doi.org/10.5278/ijsepm.3450