Human Factor and Energy Efficiency in Buildings: Motivating End-Users Behavioural Change

Human factor and energy efficiency in buildings: motivating end-users behavioural change

Verena Barthelmes[1], Valentina Fabi[1] , Stefano Corgnati[1], Valentina Serra[1-2]
1 Energy Department, Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino
2 AiCARR, Via Melchiorre Gioia 168, Milano

Abstract. Energy efficiency in buildings does not only rely on efficient technical solutions and design of the building features, but is also highly dependent on how occupants decide to set their comfort criteria, as well as on their energy-related and environmental lifestyles. In this perspective, raising user awareness among occupants by training them to adopt a more "green" and energy-friendly behaviour has become a crucial aspect for reaching energy efficiency goals in buildings. Motivating occupants to change their behaviour can become a challenging task, especially if they are expected to internalize and adopt the new behaviour on a long term. This means that information and feedback provided to the occupants must be stimulating, easy to understand, and easy to adopt in the daily routine. In this context, first methodological progresses are here presented within an European project, designed to raise user awareness, reduce energy consumptions and improve health and IEQ conditions in different typologies of demonstration case studies by providing combined feedback on energy, indoor environmental quality, and health. In particular, this paper presents one out of five MOBISTYLE demonstration testbeds – a residence hotel - located in central Turin (IT). In detail, this paper describes the setup of a tailored engagement campaign for hotel apartments and the reception area. Based on selected monitored variables, user-friendly feedback was defined to provide the users with real-time information on energy use and environmental quality, as well as guidance on how to save energy and optimize consumption profiles while creating an acceptably comfortable and healthy indoor environment.

Keywords: Behavioural change, energy use, residence hotel.

1 Introduction

Human interactions with the building systems and envelope have a significant impact on the energy efficiency and indoor environmental quality in buildings. It is well known that occupant's behaviour is a factor that affects building energy performances [1; 2; 3; 4].

The way building components and systems are used accounts for substantial uncertainty over a building's energy use and occupants' comfort. In the field of persuasive technology, various innovative systems have been realized to motivate people to change their behaviour in a more sustainable way [5; 6; 7]. For example, ambient

displays can provide users with their real-time energy consumption, serious games might educate people on saving energy in an enjoyable manner, and mobile or web applications may provide virtual rewards based on user's sustainability performances.

Menezes [8] argued that the knowledge of the "unregulated energy use" could improve to reduce the performance gap between predicted and actual energy use.

ASHRAE Standard 90.1 [9] defines "regulated" components of energy use such as energy use for heating, cooling, ventilation, interior lighting, hot water, and a few other end uses. But there is a multitude of "unregulated" energy uses within the building that are not addressed by the standard. For example, in office environment, "regulated" energy use patterns and impact within the building stock is generally well understood, while the impact of "unregulated" energy use [10], such as small power and desktop equipment, on energy consumption is not clear. "Unregulated" energy use is highly affected by occupant behaviour. Kawamoto [11] reported that desktop equipment energy use could be reduced up to 43% in an average working day. Furthermore, Mulville [10] confirmed that many employees did not switch off the desktop equipment at the end of the day, reporting that in US only 44% of computers and 32% of monitors were switched off after working hours. In UK up to 60% of employees do not turn off monitors. The reported studies demonstrated then that there is further space of research on understanding the unregulated energy use offering a significant potential for saving energy. Since unregulated energy use accounts for 73-88% of total equipment energy use [11], behavioural change programs could help on reducing energy consumption.

As Staddon [12] stated, academic research aims at directly assessing the energy savings due to behavioural change initiatives.

Perceived behavioural control is a central item in the Theory of Planned Behaviour defined by Ajzen [13] and it was demonstrated to be effective in the commercial sector [8; 14]. In particular, the study from Menezes [8] reported this factor having a major impact with respect to social norms and attitudes. Other studies demonstrated that social norms and feedback containing social comparison are effective triggers for promoting behaviour change in the working environment [15; 16; 17]. Social norms could be defined as behaviours admitted as "the norm" within a certain group of people [14]. Furthermore, social comparison or peer comparison is constituted in the human being to assess opinions and capacities.

Investigations showed that feedback and feedforward interventions methods achieved up to 20% energy savings in buildings [18]. In their studies, Fischer [19] demonstrated that occupants could be influenced in making choices by feedback information learning about consequences of their past actions. Matthies [20] reported the same result applying feedforward information (i.e. educating users before they take actions). Receiving this kind of information, people have an idea of the consequences of their possible actions on comfort and on energy consumption; thus, they could choose to perform (or to not perform) them. In this way, occupants are empowered to interact with the built environment in a more conscious way. Moreover, users learn about the control opportunities in their working area, increasing their perception of control on the surrounding environment and by consequence their comfort perception.

Moreover, scientists and practitioners, experts not only in the health sector, recognized and demonstrated that holistic environmental conditions play a significant effect on building occupants' health, although the general public has only recently started to understand the effect that this relationship can have on their day-to-day lives and well-being [21; 22].

In this context, first methodological progresses within the HORIZON 2020 MOBISTYLE project "Motivating end-users behavioural change by combined ICT based tools and modular information services on energy use, indoor environment, health and lifestyle" (grant agreement No. 723032) [23] are presented. The main goal of this project is to increase user awareness in order to reduce energy consumptions and improve health and IEQ conditions. The project will be tested in different typologies of demonstration case studies (residences, university, offices, health care, hotel) by applying a holistic approach to the engagement campaign. In particular, users will be provided with combined feedback on energy, indoor environmental quality, and health.

The purpose of the demonstration case is to illustrate and demonstrate the approach and methodologies proposed by the project. From there, the developed and derived ICT tools and services can be assessed. Case studies will furthermore be aimed at providing answers to the following questions:

- parameters that should be monitored, how the information should be presented;
- drivers and motivators influencing user behaviour;
- effects of user behaviour on energy consumption and indoor environment;
- methods and approaches for creating awareness and a long term behavioural change in users.

In particular, this paper focuses on the application of the MOBISTYLE approach to one out of five MOBISTYLE demonstration testbeds – a residence hotel located in central Turin (IT). This residence hotel is an urban long-term residence hotel that aims at achieving the nZEH (nearly Zero Energy Hotel) target and therefore represents a suitable testbed for demonstrating how energy efficiency can be further improved by transferring knowledge and tailored advices to building occupants. In this case study, specific challenges include defining tailored feedback for different end users of the hotel, such as hotel guests, but also the hotel management, receptionists, and cleaning staff. A tailored monitoring and engagement campaign was set up in four residential hotel apartments and the reception area. The monitoring campaign is based on continuous measurements of indoor environmental variables (indoor air temperature, relative humidity, CO_2 concentration), electricity consumptions of domestic appliances (washing machine, dishwasher, microwave, TV), and behavioural patterns (e.g. window opening/closings, thermostat regulation, occupancy). Based on these selected monitored variables, user-friendly Key Performance Indicators (KPIs) were defined to provide the hotel guests and hotel staff/management with real-time information on energy use and environmental quality, as well as guidance on how to save energy and optimize consumption profiles while creating an acceptably comfortable and healthy indoor environment.

2 Behavioural change strategies

Changing behaviour of individuals as a strategy for saving energy has been on the agenda for many decades. Significant progress has been made in assessing behavioural strategies, but yet there is still much more to do.

Since the 1970s, many researchers from various fields have studied how feedback on energy use impacts residential consumer understanding and behaviour [24, 25, 26]. Studies involving informative billing and periodic feedback have realized energy savings between 10 and 20%. On average, these studies found that real-time energy feedback resulted in overall energy savings of 10-15% [24, 25, 26]. It is assumed, based on theory and field research, that if residential consumers had more detailed and/or frequent information about their consumption, they would both better understand their energy use patterns and be able to change them effectively.

Two main conclusions can be drawn from a broad group of studies.

Van Houwelingen and Van Raaij [27] outlined three main functions of feedback:

- Feedback has a learning function: users learn about the connection between the amount of energy they use and the energy consuming behaviour;
- Habit formation: users put the information they have learnt into practice and may develop a change in a routine habit;
- Internalisation of behaviour: when people develop new habits after a while they change their attitudes to suit that new behaviour.

The design and the exploitation of behavioural change programs related to the energy use reduction can differ greatly when applied to residential or to office occupants [20]. Households have a direct connection between their actions and their energy monthly cost. In office buildings, energy savings campaigns are generally defined at the top level of the organisation, and there is not a direct relationship with individual workers benefits. Workers' motivation to engage in energy efficiency behaviours at workplace is therefore complex and must rely on corporate and social responsibility objectives and reinforcing social norms. Moreover, the nature of competition between individual colleagues or different offices could be a more influential driver than financial gain. There are also some reasons suggested in the reviewed literature as to why people's attitudes are different at home compared to the workplace [1;28]. For instance, at home users are isolated from others. In the workplace, different norms apply. In tertiary sector, behavioural-based strategies can become critical, since the effects of the energy saving is not directly paid back to the employees. For this reason, the financial motivation is not an effective trigger such as in the residential sector.

Further research is still needed to investigate motivations in the office environments and how to use them for promoting energy efficient behaviours in offices.

The approach used in MOBISTYLE is human- or people-centred. This approach focuses on actual needs of the users and attempts to include their habits, practices, ideas, desires in new products and services with the main goal to change their behaviour and save energy in buildings. Many scientists and public health practitioners recognize that environmental conditions have an effect on health, but the general public has only recently come to understand that this causal relationship affects their day-to-day lives.

Besides thermal conditions it is well known that indoor air quality is also strongly linked to human health.
This holistic approach is addressed to develop an effective methodology that combines together three main research areas related to the occupants (i.e. energy, indoor environmental quality and health) to gain new insights on the way people perform actions in the surrounding built environment. To stimulate users to perform more conscious actions, a combination of data collection, data analysis and elaboration, and tailored information should be provided.
As a first step, the proposed methodology relies on a data collection to investigate the operation of users on energy systems through behaviour-related data (including objective monitoring of the building and subjective data collection from the occupants). Then, data analysis and elaboration to depict human behaviour (related to energy, comfort, health) through user data (both wearable sensors and surveys, for example monitoring human presence and practices thanks to anthropological studies) allow for obtaining performance indicators. Finally, energy savings and the improvement of indoor environmental conditions and occupants' health and wellbeing are achieved by integrating behavioural communication strategies (awareness campaign).
The tailored information campaign should rely on simple and immediate information using different communication methods in order to be understood by the selected users and achieve an effective knowledge transfer. For this reason, different feedback typologies and strategies should developed to best suit the case studies. In the following, the methodology of MOBYSTYLE project is presented applied to a case study.

3 Case study description

A residence hotel, an urban hotel located in a central area of Turin, is the Italian demonstration case (Fig. 1).

Fig. 1. Views of the case study.

This case study presents a very traditional structure since the building was built at the beginning of 20th century with load bearing masonry walls. The building is heated by two condensing boilers powered by natural gas, also used for Domestic Hot Water (DHW) production. A chiller (cooling capacity 97 kW) is installed for the cooling system. Two-pipes fan coil units, placed in the false ceiling, are the terminals of the heating and cooling system (except radiators inside bathrooms). At present, the building does not have mechanical ventilation system (except for exhaust air systems in bathrooms and kitchens) and it does not a use any on-site renewable energy source.

3.1 Monitoring campaign

The application of MOBISTYLE approach will be carried out in selected apartments and in the reception of the residence hotel. All the guestrooms are comparable to small apartments in terms of internal layout and equipment as the hotel business mainly relies on guests' long-term stays.

The selected apartments are two-room or three-room flats but with similar size (between 37 m^2 and 39 m^2). The reception area has one entrance door and one window with northwest exposure.

Figure 2 depicts types and locations of the sensors installed in the two apartment typologies. In all apartments, measurements regarding energy consumption and indoor environmental quality (IAQ) will be taken. In particular, the following parameters will be gathered:

- indoor air temperature (T) [°C]: every 15 minutes;
- indoor relative humidity (RH) [%]: every 15 minutes;
- indoor CO_2 level (CO_2) [ppm]: every 10 minutes;
- electricity consumption [kWh]: every 10 minutes;
- electricity power [W]: every 10 minutes.

To understand the mechanisms of occupants' behaviours, it is necessary to monitor the behaviour itself but also to determine the cause and effect relationships that behaviours have with energy consumption, indoor and outdoor environment, and the occupants' health status.

The types of behaviour analysed in this case study can be listed as follows:

- Occupancy;
- Thermostat adjustment;
- Window opening;
- Whitegoods or other electrical devices;
- Door opening.

Furthermore, the monitoring campaign will also be aimed at measuring Physical activity (PA) in order to see if the PA pattern changes due to variability in the environment (such as climate).

Outdoor conditions during the campaign will be established by third-party outdoor data logging. Indeed, outdoor environmental variables, such as temperature, solar

radiation, relative humidity, wind speed/direction, will be acquired through an online source. The monitoring campaign is currently ongoing and takes place for a period of 24 months, from March 2018 until March 2020 (both included).

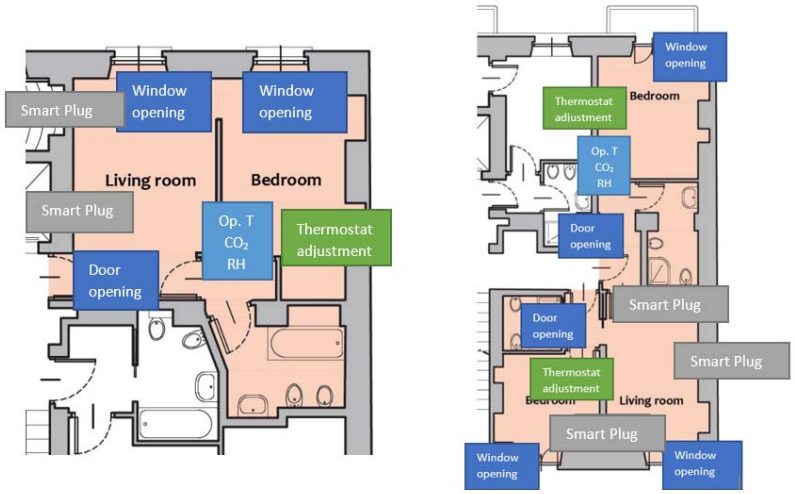

Fig. 2. Apartment typologies A (a) and B (b) and the monitored variables.

3.2 Awareness campaign

As MOBISTYLE demonstration in the residence hotel cannot be seen as a stand-alone measure, it will be supported with continuous awareness measures, information, and other feedback campaign activities for raising awareness around conscious energy usage, healthy lifestyle and the importance of living in a healthy indoor environment. Continuous interaction with all the building users of the residence hotel will be done through a mixture of communication channels to raise awareness of all end-users in the building (building manager, hotel guests, receptionists, cleaning staff). It is believed that their awareness will be increased even further when there is continuous provision of information and through different channels.

The actors involved in the project include selected guests of the monitored apartments and a focus group of users (6 participants). The focus group members will contribute with their interviews and feedback before, during, and after the measurement campaign as part of thick data collection, while the other hotel guests participating in the project will contribute with the data measured during the observation and monitoring period. It should be noted that the new and more aware behaviour encouraged at the residence hotel might lead to energy savings also in other situations the users will encounter in their everyday life. Furthermore, they may encourage other people to act according to the MOBISTYLE objectives and therefore more people are becoming aware (snow-ball effect).

Within the MOBISTYLE project, tailored information will be provided to the users of the residence hotel according to specific needs and characteristics of the hotel environment and occupants who interact with it (manager, guests, receptionists, cleaning staff). A tailored program will introduce to the building users the holistic approach of the project, its main objectives and the application at the case study. Furthermore, it will be clearly explained how data protection and user privacy is ensured.

Furthermore, awareness campaigns will promote “temperature trainings” not only as part of demonstrators but as a part of overall and healthy lifestyle and healthy ageing strategy. As example, users are educated that lowering down thermostat will not just bring energy savings but can also contribute to their better well-being and metabolic health. Moreover, it can be encouraged that users take stairs instead of an elevator as this does not only saves building’s electricity consumption but also is healthier for them. Furthermore, the clever and conscious use of appliances (e.g. stand-by mode) and lighting might help to reduce energy consumptions and can be an interesting trigger for savings costs (manager), as well, next to reducing the environmental impact of the activity.

The project and its approach has been currently introduced to the hotel manager, two receptionists and the cleaning staff. The hotel manager engages in an aware energy-related management of the building and seems highly motivated to implement the MOBISTYLE strategies in the residence hotel to further improve the energy performance of the building and to raise awareness among the hotel guests and staff - while possibly optimizing their health and comfort conditions, as well. The hotel staff (receptionists and cleaning staff) generally seems to present a slightly lower level of knowledge regarding energy-related topics and achieving energy savings for them still seems to play a less important role, however, they appear very willing to learn and to be actively involved in the project. Hotel guests have not been investigated so far.

To benefit from the opportunity of collecting a large amount of data, the data interpretation and, subsequently, the feedback provided to the users as part of the monitoring campaign in the case study will be based on a combination of standards, measurements, and relative comparisons between an established baseline and the individual units in question.

Visualization of feedback and KPIs. The feedback to the users will be given in a graphical form through an app on their mobile phones (see **Errore. L'origine riferimento non è stata trovata.**3).

Information regarding energy use is based on the overall electricity use in the apartment and on the usage of single electrical appliances (depending on which appliances are used in the specific apartments). Depending on the user's choice, feedback can be based on data from the day before, the week before, the month before or the current year. The generic profile for electricity consumption and appliances usage will be developed using the energy consumption data collected during the initial monitoring. The energy consumption data will be displayed to the end user in a graphical form using three colour levels (green, orange and red). The relationship between col-

our levels and user consumption is based on the generic profile defined during benchmarking and energy saving targets for the case study (energy saving of 16%). Users must also have the possibility to read real-time consumption and historic records.

Similarly to the representation of energy usage, the IEQ conditions are translated to the user mainly through a graphical form that involves also in this case the use of three levels of colour, depending on their trend with respect to threshold values defined by the standards [29]. Historic records and real time values of temperature, CO_2 level and relative humidity of the apartment should be provided for the end users.

A challenge of the MOBISTYLE project is that, next to feedback on energy use and IEQ, the users will be able to visualize KPIs also related to health aspects, such as the heart rate. Heart rate is the amount of contractions of the heart muscle in a certain period of time and can be influenced easily by changes in environment or activity.

Fig. 3. Example of feedback visualization (energy use) on a hypothetical application.

4 Future steps

The experimentation is on-going and divided into three monitoring phases with provision of different levels of feedback, where each of them have their own objectives:

- Benchmark definition: Monitoring phase without feedback provision to establish reference scenarios;
- Feedback provision: Monitoring phase with feedback provision on energy, IEQ and health;
- Optimized feedback provision: Monitoring phase with optimized feedback provision - this optimization is based on an intermediate evaluation that measures the impact on performance and changes in user practices by different feedback typologies.

Currently, the experimentation in the case study has started with the benchmark definition in March 2018. Feedback provision will start approximately in November 2018.

5 Conclusion

The aim of this paper was to describe first methodological progresses within the HORIZON 2020 MOBISTYLE project "Motivating end-users behavioural change by combined ICT based tools and modular information services on energy use, indoor environment, health and lifestyle" (grant agreement No. 723032). This paper is aimed at highlighting that for creating energetically sustainable and healthy environments at "human scale" it is necessary to raise user awareness through an holistic approach. In particular, this study underlines the necessity of applying a holistic approach to the engagement campaign by providing combined feedback on energy, indoor environmental quality, and health. In particular, this paper focused on the monitoring and awareness campaign in the Italian testbed, a residence hotel in Northern Italy. Indeed, this paper describes the setup and challenges of a tailored engagement campaign for hotel apartments and the reception area. Based on selected monitored variables, user-friendly feedback was defined to provide the users with real-time information on energy use and environmental quality, as well as guidance on how to save energy and optimize consumption profiles while creating an acceptably comfortable and healthy indoor environment.

6 Acknowledgements

This work is part of the research activities of an international project financed by European Community MOBISTYLE – Motivating end users Behavioural change by combined ICT based tools and modular Information services on energy use, indoor environment, health and lifestyle (Grant Agreement no: 723032.). The Authors acknowledge the support of all the partners of the project for sharing their expertise for this activity.

References

1. Orland B., Ram N., Lang D., Houser K., Kling N., Coccia M. (2014) Saving energy in an office environment: A serious game intervention, Energy and Buildings; no. 74: 43-52.
2. Andersen R.K., Fabi V., Toftum J., Corgnati S.P., Olesen B.W. (2013). Window opening behaviour modelled from measurements in Danish dwellings. Building and Environment, Volume 69, Pages 101-113.
3. D'Oca S., Fabi V., Corgnati S.P., Andersen R.K. 2014. Effect of thermostat and window opening occupant behaviour models on energy use in homes, Building Simulation, Springer, pp. 12, Vol. 7, pages 683-694, ISSN: 1996-3599.
4. Fabi V., Andersen RV., Corgnati SP., Olesen BW. (2012) Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and model. Building and Environment, Volume 58, Pages 188-198.

5. Gustafson C., Longland M. (2008). Engaging employees in conservation leadership, Proc. 2008 ACEEE Summer Study Energy Effic. Build. Available from: http://www.aceee.org/files/proceedings/ /data/papers/7 532.pdf
6. Adamson S., Using TLC to reduce energy use. (2010). Proceeding ACEEE Summer Study Energy Effic. Build. Available from: http://www.aceee.org/ files/proceedings/2010/data/papers/pdf. 2124.
7. Wood G., Newborough M. (2003). Design and Functionality of Prospective of Energy Consumption Displays". Proceeding of the 3rd International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'03).
8. Menezes A.C., Tetlow R., Beaman C.P., Cripps A., Bouchlaghem D., Buswell R. (2012). Assessing the impact of occupant behaviour on electricity consumption for lighting and small power in office buildings", 7th International Conference on Innovation in Architecture, Engineering and Construction, Sao Paolo, Brazil.
9. ANSI/ASHRAE/IES Standard 90.1-2016 -- Energy Standard for Buildings Except Low-Rise Residential Buildings
10. Mulville M., Jones K., Huebner G. (2014). The potential for energy reduction in UK commercial offices through effective management and behaviour change, Architectural Engineering and Design Management; Vol-10, no. 1-2: 79-90.
11. Kawamoto K., Shimoda Y., Mizuno M. (2003) Energy saving potential of office equipment power management, Energy and Buildings; 36: 915–923.
12. Staddon S.C., Cycil C., Goulden M., Leygue C., Spence A. (2016). Intervening to change behaviour and save energy in the workplace: A systematic review of available evidence, Energy Research and Social Science; no. 17: 30-51.
13. Ajzen, "The Theory of Planned Behaviour", Organizational Behaviour and Human Decision Processes 1991; no. 50: 179-211.
14. Mulville M., K. Jones, G. Huebner, J. Powell-Greig (2016). Energy-saving occupant behaviours in offices: change strategies", Building Research and Information: 1-14.
15. Chen H.-M., Lin C.-W., Hsieh S.-H., Chao H.-F., Chen C.-S., Shiu R.-S., S.-R. Ye, Y.-C. Deng. Persuasive feedback model for inducing energy conservation behaviours of building users based on interaction with a virtual object. Energy and Buildings; no. 45: 106-115.
16. Fogg B.J.(2003) Persuasive Technology: Using Computers to Change What We Think and Do. Morgan Kaufmann Publishers Inc., San Francisco.
17. Emeakaroha A., Ang C.S., Yan Y., Hopthrow T. (2014) A persuasive feedback support system for energy conservation and carbon emission reduction in campus residential buildings, Energy and Buildings no. 82: 719-732.
18. Meinke A., Hawighorst M., Wagner A., Trojan J., Schweiker M. (2016). Comfort-related feedforward information: occupants' choice of cooling strategy and perceived comfort", Building Research and Information; Vol. 45, Issue 1-2: 222-238.
19. Fischer C. (2008). Feedback on household electricity consumption: A tool for saving energy?. Energy Efficiency 1 (1): 79-104.
20. Matthies E., Kastner I., Klesse A., Wagne H.-J. (2011). High reduction potentials for energy user behaviour in public buildings: how much can psychology-based interventions achieve?. Journal Environ Stud Sci; 1: 241-255.
21. Kingma B & van Marken Lichtenbelt W. 2015. Energy consumption in buildings and female thermal demand. Nature Climate Change Epub.
22. Malchaire, J., d'Ambrosio, F.R., Palella B.I. 2017. Evaluation of the metabolic rate based on the recording of the heart rate. Industrial Health. Vol. 55. Pag.219-232.

23. H2020-EE07-2016-IA - MOBISTYLE - MOtivating end-users Behavioural change by combined ICT based tools and modular Information services on energy use, indoor environment, health and lifestyle - Grant Agreement no: 723032.
24. Faiers A,, M. Cook, C. Neame. 2007. Towards a contemporary approach for understanding consumer behaviour in the context of domestic use. Energy Policy 35 4381-4390.
25. Miller S. 1984. New Essential Psychology: Experimental Design and Statistics. Routledge, London.
26. Stern P.. 1992. What psychology knows about energy conservation. American Psychologist 47 1224-1231.
27. Van Houwelingen J.T., W.F. Van Raaij. 1989. The effect of goal setting and daily electronic feedback on in-home energy use. Journal of Consumer Research 16 98-105.
28. Gulbinas R., Jain R.K., Taylor J.E. (2014) BizzWatts: A modular socio-technical energy management system for empowering commercial building occupants to conserve energy. Applied Energy; no. 136: 1076-1084.
29. Standard EN 15251. (2008). In *Criteria for the Indoor Environment Including Thermal, Indoor Air Quality, Light and Noise*; European Committee for Standardization (CEN): Brussels, Belgium.