ENERGY AWARENESS IN THE OFFICE AND RESIDENTIAL BUILT ENVIRONMENTS: THE ECOFFICES AND ECOFAMILIES EXPERIMENTS

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ABSTRACT

The "Energy-efficient Smart Building" is first a Building where the energy consumption is measured (with sensors) and controlled (with monitoring systems), allowing to optimise energy demand thanks to information streams, but also a Building able to manage understanding of the users regarding their habits and living styles, adapting to their practices, and providing easily available, comprehensible and useful information for further operations through various interfaces and taking advantage of new technologies like gaming and mixed reality.

This paper introduces to two projects, one completed, one ongoing: the ECOFFICES - Energy Challenge within Offices - project [1] proposed a challenge for saving energy in office buildings in the form of a game, with an energy competition between employees taking place in an office building, and combined advanced energy metering, energy awareness and benchmarking to create an incentive scheme for energy savings. The ongoing ECOFAMILIES project [2] is investigating the "energy awareness" topic in the residential sector: following a user-centered approach, participatory workshops with families are organised with the ambition to co-design user interfaces for energy tracking and efficiency improvement at home. Issues such as type of information to be displayed, usage scenarios, type of physical device, shape and interaction to be implemented, are discussed together with the project team composed by designers, sociologists, construction, energy and IT experts.

Keywords: Energy awareness, Energy metering & sensing technologies, Eco-behavior, ICT (*Information and Communication Technologies*).

1. INTRODUCTION

Energetic and environmental challenges require today innovative solutions so as to meet targets identified by key societal challenges, typically the "20-20-20 objectives" (20% reduction in emissions, 20% renewable energies and 20% improvement in energy efficiency by 2020) set by the European Commission (EC). Decreasing energy consumption in buildings is essential in such a context, considering that residential sector and service sector are responsible for around 25% of CO2 emission, and represent 35% of energy consumption in Europe.

On the other hand, the electricity invoices, should it be for enterprises or households, are very likely to drastically increase over the upcoming 15 years, and this situation challenges the EU governments to keep this increase decent and bearable, as acknowledged by the EC: "According to all envisaged scenarios, electricity prices will raise up to 2030, before decreasing", as it is stipulated in the EC roadmap

for Energy 2050 [3]. It is worth mentioning that electricity prices are expected to be lower in a scenario based on diversified technologies and a high energy efficiency, with a real commitment to important energy savings, that can be achieved only with awareness and efforts from all.

To deal with these issues, it is now acknowledged that managing data and information is the key issue in supporting decisions and creating awareness. The so-called "Smart Building", as far as energy is concerned, is:

- a Building where the energy consumption is measured (with sensors) and controlled (with monitoring systems), therefore allowing to optimise energy demand thanks to information streams,
- but also a Building able to manage some understanding of the users regarding their habits and living styles, therefore adapting to their practices, and providing easily available, comprehensible and useful information for further operations through various interfaces and taking advantage of new technologies like gaming and mixed reality.

Indeed, the impact of use and occupancy is critical, and various surveys, such as the paper published by the Oxford's University Environmental Change Institute [4], do highlight the importance of providing feedback on building's energy consumption to users, who for most of them do not exactly know what they consume. This challenge is at the very heart of current developments at CSTB – French Scientific and Technical Centre for Buildings and Construction - through two experimental projects that are presented in this paper.

The ECOFFICES project [1] proposes a new challenge for saving energy in office buildings in the form of a game, with an energy competition between employees taking place in a building located in the Sophia Antipolis business park, and combines advanced energy metering, energy awareness and benchmarking to create an incentive scheme for energy savings. The contest is raising a high stimulation level by rewarding eco-friendly energy behavior. It provides a connection to some "energy account" profile allowing to retrieving information about the energy consumption of the previous week presented as a readable report delivering:

- Bonus, with references to good energy saving actions performed.
- Economic sanction, with references to bad energy actions performed.
- Action to do, where for both bonus and economic sanction columns are proposed suggestions to improve behaviors in order to decrease energy consumption.

The ultimate objective is to provide the user with real-time control on energy consumption and an intuitive way to understand how to modify their daily behavior that affects energy consumption.

The ECOFAMILIES project [2] is meanwhile investigating the "energy awareness" topic in the residential sector. Following a user-centered approach, 30 persons from the French Region PACA (*Provence Alpes Côte d'Azur*) participate in a series of participatory workshops, with the ambition to co-design user interfaces for energy tracking and efficiency improvement at home. Issues such as type of information to be displayed, usage scenarios, type of physical device, shape and interaction to be implemented, are discussed with field experts. Main findings from the workshops will be published in a white paper at the end of the project; therefore the needs expressed by French Families can be later on benchmarked to other families profiles and/or in other countries. In the meantime, a design studio will build-up a user interface prototype based on the ideas generated through the workshops.

2. ECOFFICES: A COMPREHENSIVE APPROACH FOR AN ENERGY CHALLENGE

The importance of user awareness in the context of energy-efficient buildings has been described in the REEB roadmap [5,6], with the expectation of visualization of energy use to become widespread in a near future, and the requirement for research to be further continued, especially through multidisciplinary pilot projects involving experts in mobility, user interfaces, sociologists, designers, etc. Energy efficiency incentives and adequate energy visualization presentations must be developed, along with behavioral change thanks to intuitive feedback given to users and operators on real time energy consumption and pricing, enabling them to optimize the control of the building and their usage behavior. Relying on

approaches based on ‘energy awareness’ and ‘competition’, the ECOFFICES project suggests a comprehensive use of ICT and includes an advanced usage analysis on the acquisition of eco-friendly behaviors generated by the challenge. It implements advanced energy meters that record electricity, water or gas usage in real time and that communicate the information to the facility manager, and dedicated user interfaces can be associated to these meters, so as to propose a service to the end-users (the occupant) to influence their behavior.

2.1 The energy challenge methodological approach

The ECOFFICES challenge, which was supposed to be a win/win situation for both the company and its employees, took place in a single company and the 47 challengers were divided into 3 teams of around 15 employees located in 3 different wings of the building. Each office was equipped with a network of sensors, each participant had access to the follow-up user interface when it became available and they were all aware of the game' rules. The prize that the challengers competed for was a team building activity, namely going out at sea looking for dolphins and having lunch together. The challenge had 3 main objectives:

- Measuring energy consumption savings realized by a collective regulation action,
- Increasing awareness of the effects that daily use of office equipments has on energy consumption,
- Improving their sustainable use of offices equipments.

In spite of a comprehensive office instrumentation (see 2.2 for details on the technical infrastructure), a detailed metrology was not possible for technical reasons, and it was not an easy task to link directly the employees’ behaviors to the building’s energy consumption measurement. Another notation system based on good / bad practices was then looked for, and a "bonus/malus" qualification system was finally adopted. In this notation system, appropriate energy saving behavior gave "bonus" (positive marks) and bad practices that increase consumption gave "malus" (negative marks). The user interface allowed the challengers to have a precise feed-back of their bonus/malus status (for instance keeping their door open when using air conditioned, or not switching off the light when leaving the office for a meeting or a break) and it helped them to understand which energy-consuming practices they had to change.

After a completion of the prototype (technical infrastructure and end-users interfaces, data gathering algorithms for recognizing behaviors) and the instrumentation of all the offices (phase 0), the experimental protocol of the ECOFFICES project consisted of 3 successive phases designed to allow comparison of competitors' behaviors before, during and after the challenge:

- *Phase 1*: Bench test without challenge (consumption reference). During this 18 weeks lasting phase, in each office equipped with sensors data consumption and behaviors have been recorded for defining a reference consumption.
- *Phase 2*: Bench test with challenge. To reveal the impact of consumption awareness upon behavioral changes, this phase was divided in 2 periods of 3 weeks each. During the first one, no feedback was provided to challengers and the user interface became available during the second period.
- *Phase 3*: Bench test without challenge (appropriation of good practices). During 4 weeks after the challenge ending, we kept recording data and the follow-up interface was still available for each participant, of course, without any comparisons of the team’s consumptions: this would allow knowing if people have adopted new sustainable behaviors - or if they go back to their previous behaviors - and if they are still interested in having a look at their consumptions.

2.2 The ECOFFICES pilot technical infrastructure

The technical infrastructure set up for the challenge, as shown in Figure 1, allowed collecting and analyzing data within the pilot building related to both energy consumption and challengers behavior within their office rooms. It included the main following components:

- The CSTBox data concentrator linked to Radio-Frequency sensors: 36 offices rooms within the building have been equipped, representing more than 400 sensors deployed overall: opening conditions,

indoor/outdoor temperature, usage of office equipments, lighting/brightness sensor, motion sensors for each employee, use of heater/air-conditioner, electricity sub-metering for each team. The 49 participating employees formed 3 teams, according to the building configuration, and one CSTBox per team has been installed. The CSTBox implements an OSGI - *Open Services Gateway Initiative* - platform, allowing remote communication with the sensors – including a check of radio reception's quality and load of batteries - data storage and pre-processing.

- A server for data analysis and treatment: raw data gathered into the CSTBox are then compressed and sent to a central FTP server. SQL treatments and C# filters are then executed in order to allow the smoothing of data by using an adequate time interval (every quarter of an hour), the measurement of energy consumptions, calculation of energy wastage, and determination of the number of bonuses and malus.
- Energy awareness web-based user interfaces, generated through SQL queries encapsulated within PHP code which connects to the database. These are accessible by the challengers through the project portal with a dedicated login and password, and give access to tailored information classified in 3 different sections – two of them being showed in Figures 2 and 3 respectively: the "Team information" interface, especially providing information on energy Bonus/Malus of a team as a whole, and the "Challenge information" interface, providing graphs to compare the teams according to their energy consumption, wastage, bonus/malus, current ranking and history since the beginning of the challenge.

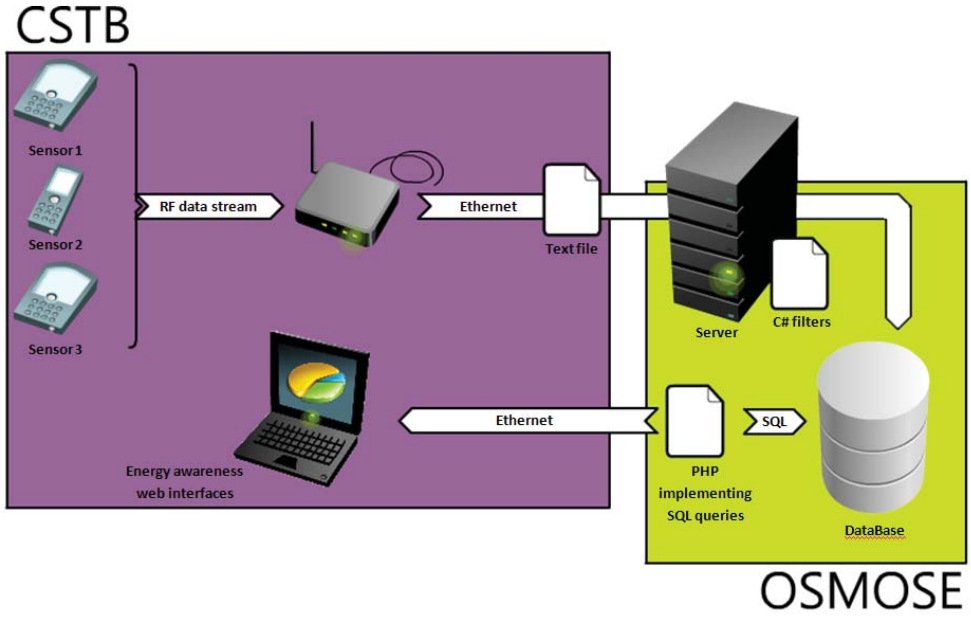

Figure 1: ECOFFICES challenge global technical infrastructure

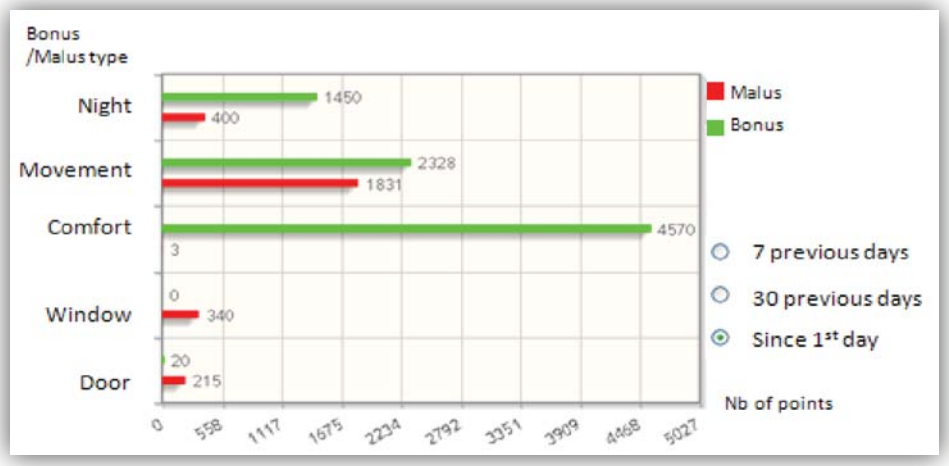

Figure 2: User interface: Bonus/Malus visualisation for an office room, since the beginning of the challenge

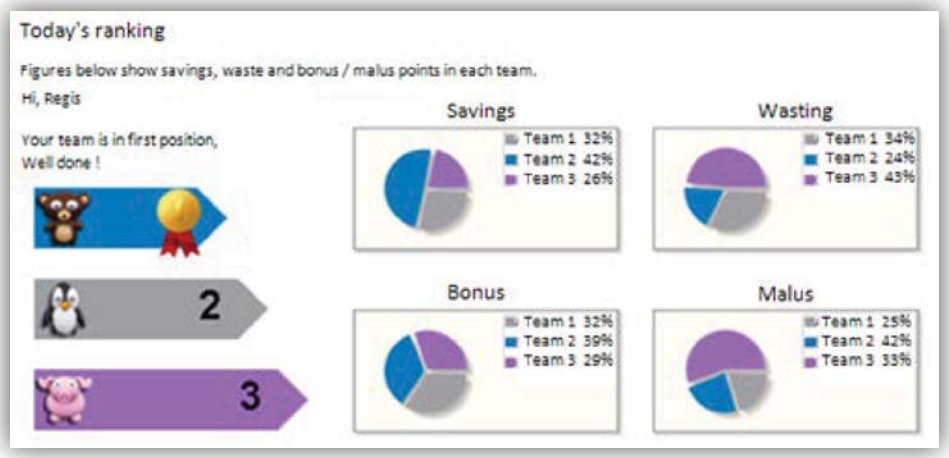

Figure 3: User interface: challenge Current ranking, savings and wastage comparisons

2.3 Main ECOFFICES results and lessons

The research and experimentation achieved in the ECOFFICES project and challenge were basically in terms of integration of various sensors and the CSTBox framework in a building, developing the analysis of information gathered, building up the various interfaces for the users, and providing with tangible socio-economic and behavioral outcomes for assessing the efficiency and reliability of the ECOFFICES concept.

From a technical point of view, integrating various technologies (especially ICT ones, including sensors, actuators, a framework like the CSTBox, along with embedded software for information gathering and analysis on-the-fly) was not the ultimate project objective, but some lessons were learnt. All devices and software dealing with information have the essential role of assembling the adequate information, and further display it in an easy and seamless interfacing, and further allow to take the appropriate decision in terms of behavior. Managing such a challenge indeed requires to be very careful with the information to be collected, as well as the way this information is collected, filtered, analyzed and further distributed, establishing a clever link between this information and the users.

To achieve such a goal in a successful way, technology components must have to be combined in an optimized way, with the right level of information and privacy, forming the ground for the appropriate

level of expected services: the ECOFFICES experimentation has allowed to identify the appropriate deployment of sensors and CSTBoxes considering the topology of the pilot building considered (CSTB premises), as well to develop an adapted organization of the information system to take an appropriate benefit of collected data: at that stage, quite a number of lessons learnt have been collected, including a detailed assessment of all ICT materials used (relevant sensors to be used, CSTBox framework), guidelines for energy information management (energy consumption baseline computation, list of bonus/malus rules, data gathering), and further insight on energy display design and user interfaces.

Data analysis, especially related to usage, relied on a combination of qualitative analysis (2 questionnaires and 3 interview sessions) and three quantitative analysis (data analysis from the sensors and meters, web logs browsing recording on the user interface).

Comparison based on quantitative analysis was not easy because the two periods (before and after challenge) were quite different considering their duration and the season. The phase 1 before the challenge was divided in two periods, depending if heating was used. Starting in February 1st, the challenge ended September 30th, with a post challenge phase lasting only one month.

The Web logs analysis showed only few visits of the user interface proposed to the challengers, probably due to the almost unchanged ranking of the three teams during the whole challenge. The questionnaire had 14 questions and 4 topics: 2 questions about personal attitudes towards ecology, 5 concerning ecological behavior and consumption knowledge at home, 4 about use of equipments at office and 3 about expectation with regards to the challenge (savings, behavioral changes…).

Within the behavioral analysis based on qualitative data, we considered 3 main points: challenge acceptance, perception of the challenge usefulness and sustainability of eco-behavior:

- The global challenge acceptance rate is very high (95%), as only 3 of the 52 invited employees did not accept to participate. 100% of the challengers answered the first qualitative questionnaire and 82% to the second one, showing that most of them maintained high interest until the end of the experiment.
- The participants' perception of challenge usefulness, that is the perception of office instrumentation as a lever for adopting ecological behavior has been assessed through the comparison of the answers given before and after the challenge about four topics : their interest for ecological questions, their ecological behaviors at home / at office and their opinion about easiness of savings for different office equipment.
- The challenge was taking place within a company employing experts in buildings and construction, some of them being focused on energy efficiency issues ; most of challengers had a high concern for ecological questions and there was fairly no decrease of interest when the challenge ended. The competition didn't give rise to new ecological behavior at home but at office, new saving behaviors have been adopted, this result being in line with quantitative analysis.

3. ECOFAMILIES: A CO-DESIGN APPROACH FOR ENERGY AWARENESS IN THE RESIDENTIAL SECTOR

The ECOFFICES project targeted the office building sector, with its specificities: it represents a part of the Built environment which is far from being insignificant. However, it appears appealing to generalize such an approach, in contexts that are different from the office building sector, as the residential one typically: the design of energy awareness "solutions" for the residential sector is a "hot topic" within the research and innovation community, with major players such as Google (e.g. Power Meter) or Microsoft (e.g."Hohm") being active in the field, although those initiatives are not yet fully successful [7]. This is why, still supported by the French PACA region and the European Regional Development fund -, a new project has started, called ECOFAMILIES [2], the objective of which is to prototype an innovative solution supporting eco-responsible behaviors within families, with the users being at a central stand thanks to a co-design approach that will embrace social science, contextual factors, usability, and interaction design research. The elaboration of the co-design methodology proposed and applied in

ECOFAMILIES is indeed expected to provide precious insights and guidelines for future developments targeted to this market.

3.1 The ECOFAMILIES ambition

The main objective of the project is to prototype an innovative « energy awareness » solution for southern French families, through participatory design. 30 persons have been recruited in the French Region PACA, to participate to iterative co-design workshops in Nice so as to express their needs and motivations related to energy efficiency in their homes. Based on those collected specifications, the ECOFAMILIES project team - which gathers specialists in smart buildings, ICT experts, academic research teams focused on behavior analysis, and an International Design studio – aims at building a new user interface prototype to stimulate eco-behaviors of families in their home.

A preliminary state of the art of the scientific litterature established by the ECOFAMILIES project team concluded that the majority of the home energy displays currently on the market do not have the functionality that consumers identify, in practice, as being critical to display design. A Dutch study [8] exhibits unstable results about the impact at middle-term of the first devices and systems available on this market of energy consumptions display (HEMS - Home Energy Monitoring/Management System) for the consumers, concluding: "*for HEMS to be effective, a deeper understanding is needed that embraces social science, contextual factors, usability, and interaction design research*". Those preliminary conclusions have shaped the ECOFAMILIES project objective: to prototype a new "energy awareness" solution for the residential sector, following a fully user centred design approach, involving a selection of voluntary families with a wide variety - age, sex, SCP - of profiles.

3.2 The ECOFAMILIES methodology and expected outputs

A call for participation has been published at the end of 2011 to identify at least 30 volunteers in the French Region PACA. Those families have been invited to follow the user-centered design methodology which has been established for the project, with the ultimate aim to define specifications and guidelines for the new "energy awareness" prototype to be developed. The complete methodology includes:

1. Participation to 3 co-design workshops (from March to June 2012) with the whole multi-disciplinary ECOFAMILIES project team. Workshops are used to gather knowledge about barriers, understand participants' experiences, their visions of a topic and their attitudes towards specific scenarios. The objective is to better understand users and collect additional insights on their lifestyle, visions and requirements, as well as to stimulate a dialogue between participants on the relevant topics, and identify possible design directions for the concept design phase. Such workshops allow researchers to better understand the user needs and to co-design with them the "ideal" energy awareness tool. The prototype will follow an incremental design, and its evolution will be presented to the families at each co-design workshop (Figure 4).
2. An online questionnaire to define families profiles, and answer preliminary questions related to energy consumption consciousness, information channels, and engagement within the community. This questionnaire – filled-in by the families at the beginning of the research process - will help the research team to explore areas associated with both the private and the public sphere of research: awareness and practices related to the domestic energy consumption, relationships inside the community, energy consumption trends and dynamics, social collaboration initiatives.
3. A dedicated online blog, allowing a continuous interaction between the families and the project team throughout the project: the blog is used for launching short surveys / polls closely related to the prototype design, and for regularly publishing updates about the project as well as the main outcomes and photos from the co-design workshops. Families are offered to comment and react to any article published.
4. A documentary film is recorded during the project : the objective is to capture families involvement in the co-design process, and to collect their feelings and perception of their role and in-

volvement within this particular project. We expect to show through the film the incremental expertise gained from one workshop to another on the topic. At the end of the project, the film will be presented to the families, and a follow-up debate will be organized.

5. An eye tracking system, used near the end of the research process, will allow a precise analysis of the perception and use of interfaces by the volunteers: by recording eye movements, facial expressions, and interaction with the prototype, it will provide additional validation elements for both contents and design.

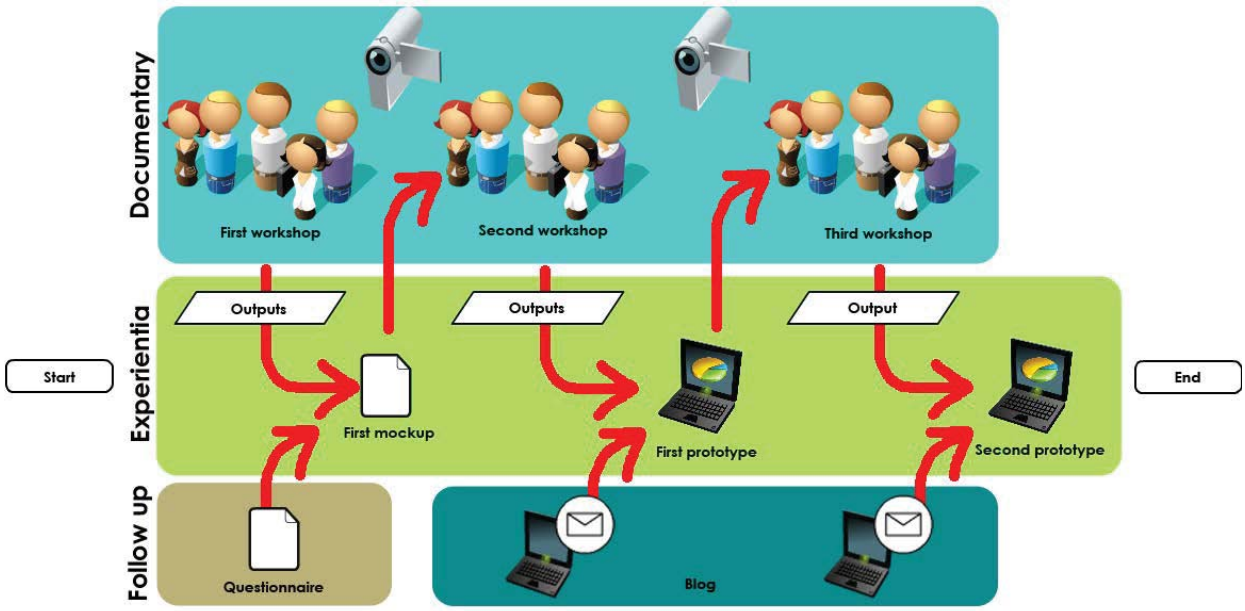

Figure 4: ECOFAMILIES co-design process

The two main final outputs to be produced by ECOFAMILIES are:

1. The publication in a scientific paper of the lessons learnt through the co-design process: the complete analysis of the needs expressed by the families during the co-design workshops, through the surveys and interviews. Those needs will be of course specific to the Southern French Families participating to this experiment - the project being supported by the French Region PACA and the European Regional Development Fund - but the objective being to later on benchmark those results to other projects and initiatives focusing on the same topic from other regions and/or countries.
2. The developed "energy awareness" prototype based on the above-mentioned specifications. It is worth mentioning that the prototype will not be tested in real conditions in the families homes within the framework of the ECOFAMILIES project - being a one year project -, although this task could constitute a logical follow-up to ECOFAMILIES through a new project.

3.3 ECOFAMILIES: some preliminary outcomes

The purpose of the last co-design workshop (June 2012) is to present the last prototype version built according to identified user needs and wishes. Before this step, ECOFAMILIES produced some preliminary outcomes :

- Current tools (meters, bills, etc..) do not meet the families' needs because they are perceived as non-interactive, not issuing clear and complete information and sometimes unsightly.
- The elaborated "design objects" - e.g. "Energy Aware Clock" [9], "Flower-lamp" [10] - are appealing but are considered inadequate by the families in terms of information and interactivity.

- It appears that dedicated tools are judged rather negatively. Indeed, families don't want to buy a new "gadget" and are afraid about not using it on a long-term basis. Families, who own already several digital tools (computers, Net-Book, Smartphone, tablet, etc..) are not willing to get an additional device.
- Web interfaces appear to be enjoyed by the majority of respondents because of the simplicity to watch data from any device anywhere (Smartphone, tablet or computer).
- Regardless of the device, it is important that information pattern(s) are clear and easily understandable. It must also be attractive and even fun and not too "austere" (diagrams, graphs, charts, histograms,…).
- A warning & alerts notification system is required by all volunteers. Consumers want to be alerted (through a colored visual notification for instance, or a text message on the phone) when problems occurs, and even more particularly when they are absent from their home (during holidays, working days, ...).

4. CONCLUSION AND FUTURE WORK

This paper presented two experimental projects at the crossing of issues related to energy efficiency in the built environment and the impact of customers and inhabitants behaviors: those projects relied on Regional experiments, but with a European impact thanks to the results dissemination through the wider European Network of Living Labs through the "ICT Usage Lab" Living Lab [11]. The common underlying thought is clear: to consume energy in a more clever way, thanks to accurate energy monitoring relying on data aggregation systems to analyse - and further optimise - the energy use by users, taking into account the impact of their own behaviors. Whilst the ECOFFICES project, the ECOFAMILIES impact will be a refined vision of families needs, motivations and barriers to eco-behaviors and eco-life-style in their homes, a deeper analysis on the design of "energy awareness" solutions, which should become more and more popular following the massive roll-out of smart energy meters in many EU countries, and ultimately a new "energy awareness" prototype built *with* the end-users.

Combining the information network with the energy managed and the user awareness is a basis for future optimization of energy consumption in the built environment – providing a mean to the user to be an active (if not central) protagonist of energy efficiency in buildings. Future building energy management systems will fundamentally rely on the various information provided by all equipments, devices, sensors, indeed all connected objects installed in buildings, with all data being collected through some Internet box and analysed by the central system, potentially according very fine-grained protocols. This will constitute a basement to help in the future the users to better grab the importance of mastering energy consumption at an individual scale, while ensuring a constant comfort for the inhabitants. Future perspective of this work is to be considered at 2 levels:

- Regarding ECOFFICES, the re-deployment of such experimentation in various different cases of office buildings – potentially identifying general rules for replication, as well as specific parameters that are to be calibrated for each new deployment;
- About ECOFAMILIES, *and at the time of writing this paper*, the last part of the project will consist in prototyping the ECOFAMILIES system and interfaces in an apartment-test (laboratory) in CSTB Sophia-Antipolis, used to configure and test (ICT-based) solutions for smart buildings. This apartment is a physical reproduction of a real one (with bedroom, kitchen, bathroom, etc.), moreover providing with the appropriate flexibility and modularity so as to quickly and easily integrate new technological components. Volunteers in the selected families having participated to the co-design workshops will be invited to test and assess the prototype.

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