From awareness to energy saving: using user engagement to change occupants’ behaviour

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Abstract. Scientific literature in the last years provided clear evidences of the determining role occupants play in achieving the highest standards in energy saving and how bad management of HVAC systems, hot water, openings, and electric equipment, may result in increased consumptions, energy waste, and lack of comfort. Based on such assumptions, a campaign to promote occupants’ awareness about energetic implications of many daily actions has been launched at the beginning of 2018, by means of a smartphone app. Meanwhile, a selection of the most active users has been given a control unit capable of monitoring occupants’ movements, electric energy consumptions, indoor temperature and relative humidity, illuminance and carbon dioxide concentration. Such parameters can be accessed by means of another app, allowing the users to immediately see the effect of their actions in terms of energy savings and indoor environment quality. In addition, it is possible to monitor occupants’ habits, set (and send) specific alerts, and verify whether the suggestions given by the app actually induced relevant changes in users’ behaviour. The paper presents and discusses a preliminary set of the collected data and provides evidences of the positive feedback induced by the combined use of both apps and the control unit.

1. Introduction
Buildings have a major role in energy consumptions (about 40% of the total), and consequently on the emissions of green-house-gases (about on third of total). Possible strategies to reduce such impact involve actions on the building envelope and use of more efficient HVAC systems, which may become quite expensive when applied to existing buildings [1], while in case of new constructions the NZEB paradigm, fostered by several national regulations [2] has become a standard but, given the relatively small number of such buildings compared to existing ones, the real impact remains low.

Within this framework, an increasing number of studies showed discrepancies between expected energy savings and those resulting from measurements [3,4], thus pointing out a determining role of the occupants in influencing this mismatch. Consequently, in the last years, a considerable number of studies have been carried out in order to understand how (and how much) occupants’ behavior may affect the energy performance of buildings [5-7]. Some studies pointed out the difficulty of getting significant results when environmentally sustainable changes in occupants’ behavior are taken into account [8], while others pointed out a major role of cultural background [9] and motivation [5]. Among the possible strategies to get the final user involved in the process and sufficiently motivated to take action, two major trends can be considered [10]. On one side serious games and gamification are considered valuable tools to increase occupant awareness and stimulate behavioral changes also by means of some kind of reward mechanisms [11]. The distinction between the two is somewhat subtle, as serious games are defined as real games developed with the intention to be more than entertainment, while gamification refers to the use of game elements in non-game contexts to improve user engagement. A further distinction that can be made depends on the way the user is involved. In fact, reward-based
gamification, involving the use of points, badges, etc. is considered to be useful to foster short-term actions. Conversely, meaningful gamification, mostly based on exposition, information, reflection, and engagement, is suitable to get more long-term effects.

In parallel with game-based actions, the second trend which is getting more and more attention, is based on the use of smart-metering tools capable of collecting data about energy consumption and indoor environment parameters, and making them available through web or smartphone interfaces [12-14]. A number of tools also provides solutions for engaging users in an interactive and participatory process, aiming to monitor and improve their behavior, promoting sustainable and green attitude. However, according to a recent review [11], users generally experience sensors in a passive way, and consequently they do not remain engaged for long periods [15]. Possible solutions have been proposed, trying to combine the “gaming” aspect with “metering” one, also allowing users to define their own energy-saving rules, as well as, offering them artificial intelligence tools capable of counselling the users, or just replace them.

The present paper describes the preliminary results obtained in terms of user engagement and change of behaviors in favor of energy aware attitude, resulting from the combined use of a smartphone app and a smart metering control unit. The app, as described in Sec. 2.1, using the gamification principle, guided the users to become aware of the energetic implications of their everyday actions, allowing to collect points and remain involved in understanding more in-depth aspects. The control unit, as described in Sec. 2.2, allowed collecting several measures related to energy use and indoor comfort parameters, making them accessible through another app. Sec. 3 summarizes the most interesting results obtained by means of the gamification app and of the control unit. Sec. 4 finally provides some concluding remarks.

2. Methods
Considering the results of the previous researches, a combination of different approaches was considered as the most effective strategy to increase user engagement both in terms of motivation and long-term effects. The “Beeta system” is an ecosystem that aims to increase people awareness about energy efficiency in buildings and support virtuous behaviours in terms of energy savings. The ability to increase users' awareness through effective and continuous engagement makes Beeta different from other similar systems; this is achieved by means of two distinctive elements:

- The free app “Beeta Game”, to interact with the system by means of a gamification approach;
- The “Beeta Box device”, a multiprotocol smart gateway/edge computer with a multisensory user interface and with the “Beeta Premium” monitoring and control app.

2.1. The gamification app
The Beeta Game app has the aim to increase the awareness and virtuous behaviour of users in terms of energy savings in homes and buildings. By playing an original game arranged in “missions”, the user provides information needed to describe features of the home, energy consumptions and potential energy saving, and receives points, feedback and notifications about the Beeta Class. The Beeta Class is a simple classification of the energy efficiency of the house and its systems (heating and cooling), obtained via proprietary algorithms based on building structure, plants, and user habits. The more missions the user will complete the more accurate the Beeta Class will be. Three types of missions can be completed:

- Blue "special" missions to define home structural parts, as well as systems and their consumption;
- Green Missions concerning the user's habits and behaviours or other situations that influence the energy consumption (e.g characterization of individual appliances in terms of certified consumptions as given by labelling system);
- Orange Missions with questions related to the user's opinion regarding specific energy issues.

In Premium mode, an AI-machine learning algorithm will improve the accuracy of consumption estimates and savings suggestions, increasingly personalized thanks to the analysis of data collected from sensors.
2.2. The control unit

The core of the proposed system is control unit named Beeta™ Box which is based on a LINUX Embedded platform, allowing the implementation of software solutions which can run in a standalone mode or connected to a remote platform. The control unit uses standardized protocols and communication interfaces that ensure full configurability, modularity and scalability of the proposed solution. The embedded software can be upgraded remotely, so to ensure that both devices and supported protocols are always updated, compatible and aligned with the latest market evolutions.

The control unit is equipped with several I/O connections, including:

- wireless connectivity: ZigBee, Wifi, Bluetooth, Z-wave, WM-Bus 169MHz, NB-IoT;
- wired connectivity: RS485, Gigabit Ethernet, S0 and dedicated I/O;
- 3 USB ports can be used to easily expand the Smart Gateway to include modules like GPRS/UMTS/4G or other dongle to integrate more protocols if needed;
- the smart power supply can communicate directly with electric energy meter complying with CEI CEN/CLC/ETSI/TR 50572 and EN 62056-x-x

Thanks to the above features the system can be used in combination with third party smart devices or software systems, to monitor environmental conditions, utility energy meters, appliances, specific loads and to control actuators like windows shutters, smart plug, lights or to generate alarms. The processing unit allows to execute locally algorithms for controlling and monitoring the building.

The whole system can be controlled by means of a user-friendly app (named Beeta Premium) that can monitor and control any kind of parameter, particularly energy consumptions. Thanks to the app the user can read the electric energy smart meter, obtain instantaneous (real-time) values, as well as averaged over daily or weekly time intervals. In addition, indoor environment quality parameters are also available, so to stimulate awareness on the actual relation between consumptions and comfort conditions.

3. Results

3.1. Statistical results derived from the gamification app

The gamification app was used by a total of 1174 users, most of them located in Apulia (31%), but with significant contributions from other Italian regions, and, in particular, Lombardy (16%), Lazio (8%), Piedmont (7%), Veneto (6%), Tuscany (6%), Campania (5%), and Emilia-Romagna (5%). In terms of number of occupants, 8% of the houses were occupied by just one person, 29.6% by two persons, 27.4% by three persons, 24.8% by four persons, and the remaining 9% by five or more. The large majority of the users (55%) lived in flats, 11% in semi-detached houses, and the remaining 34% in single or detached houses. In terms of period of construction, a 30% of the houses were built after year 2000, 60% between 1946 and 2000 (more or less evenly spaced among different decades), and the remaining 10% in houses built before the WW2.

With reference to the heating system, about 40% of the users stated that the system was new or revamped with good insulation. In 86% of the cases the heating was autonomous and could be directly controlled by the user, while in the remaining cases it was centralized. Among those with autonomous system, 32% is using a condensing gas-heater, 45% a standard gas-heater, and the remaining 23% is using heat-pumps or other electricity powered systems. Setpoint temperatures were kept below 18°C in 24% of the cases, above 22°C in 20% of the cases, and within the 18-22°C range in the remaining 46% of the cases. Finally, with reference to the number of hours in which the heating systems is turned on, the large majority of the users (about 80%) declared a number of hours lower or equal to the maximum allowed by National regulations for the climate zone they live in, and about 30% (of the total) never exceeds 4 hours of operation. Finally, with reference to thermostat and regulation, among the 412 users who responded, 66% only had a thermostat, and 27% had thermostat and thermostatic radiator valves.

Overall, even though a number of incorrect behaviors were observed, the big picture appears rather positive in terms of declared quality of the heating system and its control system, together with the use of other electric appliances. Anyway, a more detailed investigation carried out on the sample of users who were given the Beeta Box allowed detecting several critical conditions.
3.2. Using measured data to detect incorrect occupants’ behaviors

In order to identify possibly incorrect behaviours, the time history of all the available parameters measured by the control unit and its connected sensors was analysed. The basic set of data included indoor air temperature and relative humidity, illuminance, proximity, CO2 concentration, and electric power load. The data set was analysed by means of an automated procedure in order to identify the presence of occupants, the contribution of artificial lighting, and window opening time. Once these additional data were determined, a combined analysis was carried out also taking advantage of detailed information available from the app survey.

As an example of the possible outcomes, Figure 1a shows the plot of indoor air temperature in a house with a clear overheating problem. The setpoint temperature schedule includes four time slots in which temperature is set to 20 °C (red areas in figure), while in the remaining intervals a setback value of 18°C is assumed. It can be clearly observed that temperature measured by the control system sensor is well above setpoint values, reaching a maximum of about 23°C. Explanation for this behavior was found in the fact that the sensor and the thermostat are in different parts of the house (the sensor in the living room and the thermostat in a corridor, close to doors and windows). Possible inaccurate readings from both temperature meters are also possible, but the distance between the two seems more likely to cause the observed behavior, with a significant waste of heating energy. A confirmation of this behavior can be found by plotting simultaneously temperature and CO2 concentration (Figure 1b). In this case it can be observed that the sudden decrease in CO2 concentration taking place at around 8:00 in the morning and continuing up to mid-day is typically associated to the opening of one or more windows. So, the fact that, in this case, temperature continues to raise even after 8.30 (when the setpoint temperature becomes 18°C) means that the open window was closer to the thermostat than to the monitoring sensor and that at thermostat location temperature dropped below the set point. At 13.00, when occupants come back home for lunch, CO2 concentration raises and then remains nearly constant, likely signaling that the windows were closed and that they were probably out till evening.

![Figure 1. Plot of indoor air temperatures monitored in a home with single thermostat and monitoring temperature sensor located in two different rooms. a) Normal operative conditions; b) Window left open in the morning.](image)

Another example of incorrect behavior was found considering temperature variations in the house of a different user (Figure 2a). This time results from two sensors were available. One located in the main living room and the other in a study room (on a different floor). The rooms have independent heating systems controlled by local thermostats, so this explains why there is no correlation between the two data sets. No regular pattern can be observed. In fact, the user confirmed that setpoint temperatures are manually set to a maximum/minimum to just switch on/off the system. This also explains why in the first room temperatures are always above 20°C and can reach values well beyond 22°C in several occasions. In the second room, less frequently used, the more limited heating time prevents the temperature from raising significantly, but occasionally high spikes can also be observed. Another user showed a similar situation (Figure 2b), with a manual control of the heating (no regular pattern observed), but completely different results, characterized by indoor temperatures well below comfortable conditions and slowly drifting according to outdoor temperatures. In both cases the manual control of the heating caused increased discomfort.
3.3. Examples of positive feedback and modified occupants’ behaviors

By means of the same techniques used in the previous section, it was also possible to find out virtuous behavior examples, although they appeared comparatively less frequently than incorrect ones. In terms of activities to limit electric consumptions, the most frequent actions involved limiting standbys consumptions and using energy saving washing cycles. As an example Figure 3a shows that the user switched off some constant loads (likely devices that usually operate in stand-by mode) right before Christmas vacations, so that for the subsequent 15 days during which the house was not occupied (not entirely shown in figure), an average saving of 0.5 kWh per day was obtained, corresponding to about 30% of energy absorbed during unoccupied conditions. Another action frequently reported is the use of energy saving cycles for dishwashers or washing machines. Many users declared that they originally preferred faster or more intensive dish-washing cycles which, as shown in Figure 3b, proved to require up to 1.8 kWh/cycle, while “eco-mode” cycles, required about 40% less energy (1.1 kWh/cycle).

Actions to limit heating energy consumptions were less frequent to find, possibly because the dependence on many variables and the need to ensure comfort conditions for several occupants makes it difficult for users to enact correct strategies. However, the possibility to constantly monitor indoor air temperatures, combined with the availability of programmable thermostats, offered some users the opportunity to optimize heating cycles so to avoid overheating (Figure 4). In addition, as the control unit also provides programmable visual feedback, the user requested to receive an alert as a function of CO2 concentration, thus avoiding unnecessary ventilation that could dramatically reduce indoor air temperature. As shown in Figure 4, the resulting indoor temperatures remain within a temperature range of about 2°C, respecting national regulations and ensuring optimal comfort conditions during occupation hours.
Figure 4. Plot of indoor air temperature (blue line) and CO₂ concentration (red line) in a house with programmable thermostat and alerts to prevent unnecessary ventilation.

4. Conclusions
Occupants’ behaviour represents one of the most powerful factors influencing energy use in households. Gamification and smart metering are known to contribute to improve awareness of energetic problems and stimulate engagement in taking long term actions. An ecosystem composed by different apps, a control unit, and several sensors has been designed to promote a more sustainable lifestyle and obtain measurable energy savings. A preliminary set of data was analysed in order to obtain general statistical data about the sample of users involved, and to detect typical patterns of energy use in household environment. Results pointed out a number of incorrect behaviours, mostly related to improper management of the heating system. Smart metering of electric consumptions proved to be effective in letting users realize how much energy different appliances need, and stimulated to use eco/green programs. Conversely, monitoring indoor temperatures had little influence on bad habits in heating system management, possibly because it was harder to understand the energetic implications of certain actions. At this stage, only in limited cases, and in particular when programmable thermostats were available, it was possible to observe energy-aware behaviours. Thus, more specific engagement tools will be needed to stimulate users to take action and heat their homes more wisely.

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