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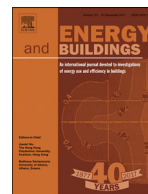
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Analysis of energy consumption profiles in residential buildings and impact assessment of a serious game on occupants' behavior



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ABSTRACT

The paper has a focus on energy consumption habits, trends and intervention strategies in residential buildings, mainly through the serious game approach with a combination of direct consumer feedback through smart metering. More than 150 homes in France and Spain have been involved in the research experiment and the consumption habits of approximately 50 homes were deeply analyzed. The applied methods, processes, results and findings of the monitoring data analysis are presented in the paper with two aims. First, consumption profiles and trends were determined for apartment homes with regard to heating, domestic hot water and electric consumption. Second, the impact of a serious game experiment was assessed comparing energy consumption, indoor air temperature and users' habits (based on questionnaires) before and after launching the experiment.

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1. Introduction

The influence of occupant behavior on energy consumption in buildings is getting increasingly significant as the overall energy demand of the buildings is substantially decreasing due to the highly ambitious energy performance requirements. The performance gap of nearly or net zero buildings is widely known and has been a hot topic recently. A study dealt with identifying the actual gap between the designed and actual consumption of the building, where they concluded that the behavioral aspects have a significant role in this area [1].

The recent jump in smart meter technology opened new perspectives in monitoring occupant behavior in buildings and can be used for several different applications, such as occupant behavioral modeling, fine-tuning of certain design values or load forecasting.

This paper has a focus on testing intervention strategies in residential buildings, mainly through the serious game approach and combines it with direct consumer feedback through smart metering.

The research was carried out within the Horizon 2020 Greenplay project aimed at raising awareness among citizens through the implementation of a real time monitoring energy consumption

platform and the development of a serious game. The project ran from March 2015 to August 2018.

The specific objective of the developed serious game (entitled "Apolis Planeta") and the related eGreen monitoring platform was to stimulate residents to use their homes in a more energy efficient way. More than 150 homes in France and Spain have been involved in the pilot activity and the consumption habits of approximately 50 homes were deeply analyzed.

The paper presents the applied methods, processes, results and findings of the monitoring data analysis with two main objectives. First, consumption profiles and trends were determined for apartment homes with regards to heating, domestic hot water and electric consumption. Second, impact of the Greenplay solution (the serious game approach) was assessed comparing energy consumption, indoor air temperature and users' habits (based on questionnaires) before and after launching the experiment.

2. Methodology

2.1. Literature review

The impact of occupant behavior on energy consumption was investigated in numerous research articles [2], including research on how changes in occupant behavior affects the energy consumption [3–6]. However, it is also important to note that the presence and behavior of occupants have a different impact on

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energy consumption [7]. It can also be identified that there are several gaps in the current research such as systematic approach, larger scale empirical evidence, socio-economic status assessment and the effect of occupant behavior included in policies [8].

Most of the occupant behavioral studies were conducted in office buildings, where the main occupant-related energy consumption is electricity, which is easy to measure, however there is also need for occupant behavioral patterns in the residential sector [9]. In the residential sector the greatest challenges are the greater diversity in occupant behavioral patterns and the financial barriers for large scale monitoring, however for smaller pilot projects it is possible to carry out detailed measurements [10]. However, the recent jump in smart meter technology made it available to monitor occupant behavior in different buildings, and this can be used as a tool for several different applications, such as occupant behavioral modeling or load forecasting, but it has also brought up another challenge, which is the problem of big data analysis, which needs to be addressed as well [11,12].

In the case of residential buildings the smart metering of electricity consumption is the most common, where daily profiles are identified [13,14]. Heating and cooling consumption patterns are harder to measure, however when the heating as well as the cooling is based on electricity it is possible to measure the consumption and create the profiles [15]. It must not be forgotten, however, that in case of heating and cooling the building physical characteristics, location and the quality of the technical building systems play a more important role in consumption than human factors. Also it is possible to supplement the smart meter measurements with surveys which could yield a better understanding of occupant behavior and user patterns [16]. While establishing the demand profiles it is important to keep in mind, that there are also changes in behavior and the profiles can change, thus this phenomenon should be also addressed [17].

In order to process monitoring data, widely used methods are available for scientists such as energy signature, heating degree day corrections and statistical data processing. The “ICT PSP Methodology for Energy Saving Measurement” developed in 2012 [18] and the “Methodology for energy-efficiency measurements applicable to ICT in buildings (eeMeasure)” developed in 2011 [19] give a very comprehensive and practical guidance on data processing. The two methodological documents have been produced as part of the eeMeasure project in order to promote good practice and consistency in the reporting of ICT-PSP project results. The original basis for savings calculations within the ICT-PSP projects was a modified version of the EVO International Performance Measurement & Verification Protocol (IPMVP) [20].

It is also important to note that solely the measured data is not enough to draw conclusions about the energy consumption habits. The smart meter data need to be processed and filtered and then presented to the users to give feedback about their consumption. One way of giving feedback is to install in-home displays in the building, thus the occupants can see their consumption and make changes in their behavior to save energy [21].

By measuring consumption and creating consumption profiles [22,23] it is possible to make more accurate building simulations [23,24]. By performing individual building simulations it is possible to make territorial assessments of energy consumption with building typology and bottom-up modeling, which can be useful for policy makers as well [25,26].

This paper has a focus on testing intervention strategies in residential buildings, mainly through the serious game approach and combines it with direct consumer feedback through smart metering. The idea of using smart meters, real-time feedback, or variable tariffs to influence energy use by private consumers is not recent. However, smart metering opened up a new way of evaluating consumer behavior. A novel contribution of the study is

that conclusions are supported by multi-methods applied with the involvement of a large number of homes from three different pilot areas with different circumstances and climate and it covers heating, domestic hot water and other electric consumption separately. In case of this project only homes with solely electricity usage were selected, thus the measurement of different consumption types was easier. Focusing on homes with electric heating has the advantage that energy need and consumption are close to each other, because electric systems can be characterized by high efficiency factors and low losses. Thus, conclusions on consumption can be extended for demand. However, this statement is valid only for daily or longer time periods, for hourly analysis there can be time gaps between consumption and demand due to storage. Furthermore, energy consumption trends are changing with time even in short term and previous results can get out of date in a relatively short time.

A serious game is “a game in which education (in its various forms) is the primary goal, rather than entertainment” [27]. Applications based on Serious Game are now worldwide and in many sectors such as health, defense, education, and sustainable development. We can find in the literature a very rich typology and synonyms are linked to this topic [28]: Educational games, Simulation, Alternative Purpose games, Edutainment, Digital Game Based Learning, Immersive Learning Simulations, Social Impact Games, Persuasive Games, Games for Good, Synthetic Learning Environments, Games with an Agenda. This diversity of terms is due to the numerous stakeholders with an interest in the Serious Game and the diversity of their approaches. According to other work [29], we can elicit 8 principles to consider when designing a serious game: (1) encourage motivation and get users to engage in the situation, (2) identify the knowledge that users will have to handle, (3) give users a freedom governed by rules, (4) introduce instructional elements that allow users to have feedbacks on the strategies they adopt, (5) allow error, don't dramatize the failure, (6) enhance the interaction between players, (7) take into account the emotional aspects and (8) integrate playfulness phase in the learning situation.

Research shows that direct feedback in home displays could save up to 15% electricity [30]. However, as stated by Paetz et al. “although providing information and feedback is a precondition, it may not be sufficient on its own” [31]. Then, the use of games appears in the 2000s with first serious game type as for example Professor Tanda [32]. The primary objective was to increase the awareness of people then let them reduce their electricity consumption. One difficulty of this game was that consumption data were not connected to the game and users are required to enter them manually. Thus the pervasive games appear to reduce electricity consumption. Pervasive games are often referred to games that extend beyond the traditional interface into the real world [30]. Nine projects working on pervasive and persuasive gaming for energy conservation are identified (Table 1). These projects are partially presented in the work of Johnson et al. [33]. All of these games use the principle of “reward” as encouragement but they differ a lot in terms of functionalities: advice generator, quizzes, use of cooperation and/or competition and video game. The advantage of gamification is that behavior change and thus energy saving is stimulated by rewards but also by the social interaction through cooperative challenges. In fact, literature suggests that the integration of socially aspects as competitiveness and comparison feedback is more efficient in individual energy saving [34–38]. From our literature review, the closest solution to our one is the Social Power [38,39]. Indeed, except the video game feature, Social Power provides the same features as ours (Apolis Planeta). Moreover, it focuses on the challenge and social interaction in energy saving. One project does not appear in the Table 1 because it is a specific case. Indeed, Gnauk et al. [40] propose solution of

Table 1
Projects working on pervasive and persuasive gaming for energy conservation (PART 1).

Name	References	Comparison according to the functionalities				
		Advices	Quizzes	Cooperation	Competition	Video game
Eco Island	[41]			Yes	Yes	Yes
Power Agent	[42]	Yes		Yes	Yes	Yes
Power Explorer	[43]				Yes	Yes
Energy Life	[44]	Yes	Yes	Yes	Yes	
Gaea	[45]	Yes	Yes		Yes	
LEY!	[46]		Yes		Yes	
Energy Battle	[47]	Yes		Yes	Yes	Yes
Climate Race	[48]			Yes		
Social Power	[38]	Yes	Yes	Yes	Yes	

Table 2
Projects working on pervasive and persuasive gaming for energy conservation (PART 2).

Name	References	Sample	Duration	Energy saving
Eco Island	[41]	20 (6 families)	4 weeks (2 weeks of exp.)	6% (eq. CO2)
Power Agent	[42]	6 players (and their family)	10 days	After effort (1 h): ~34% During Game period: ~22%
Power Explorer	[43]	15 participants (12–14 years old)	57 days (monitoring after) 1 week	After the game: ~0.2% During game: ~16%
Energy Life	[44,49]	24 participants (34.87 years on average) = 8 households	10 weeks post exp. 3 months	14% (not statistically significant) Null (reduction of the accesses)
Gaea	[45]	No quantitative but usability studies		
LEY!	[46,50]	Focus on architecture game design for environmental awareness		
Energy Battle	[47]	17 households (2–5 persons) 10 households	4 weeks test 4 weeks after	24% Very variable values according to households
Energy Explorer	[51]	Focus on methodology and game description		
EnerGAware project	[52]	Focus on game description		
Social Power	[38]	108 persons (46 playing actively)	13 weeks	~5%

gamification in demand dispatch systems. This solution does not focus directly on the energy saving but on the behavior change according to the flexibility of renewable energy sources.

In addition, the state of the art presented in the Table 2 shows that, for the majority, solutions enable a reduction in energy consumption as the solution is used. However, energy saving does not persist when game ends. That is why, we choose to perform a long term experiment. Once again, the work of Castri et al. [38] is the closest of our approach with more than 100 persons in the experiment.

2.2. Experimental overview

The concept map of the research is presented in Fig. 1 expressing the applied multi-methods, experimental design and data analysis. The entire project duration was 3.5 years. We developed a serious game and an online energy monitoring platform in order to stimulate energy saving and involved 157 homes in the experimentation. The energy performance data subject to evaluation were built on different pillars: energy audits, online surveys and monitored energy consumption.

2.3. Concept of the serious game and the eGreen platform

The Greenplay solution was composed of 3 main connected components:

- Data collection is provided by smart meters to monitor electrical consumption installed in more than 150 homes for about 1.5 years
- A customized platform eGreen (<http://www.egreen.fr/>) to inform occupants about their own energy consumption. This platform is accessible through login and password sent to each

dwelling in order to help people to reduce their consumption with customized advices and questions that provide “Greenies” (points). Diverse advices are proposed to occupants and have been designed based on scientific literature and are to be spread through the eGreen platform and the Apolis Planeta serious game using the sub-module called smart advice generator. The smart advice generator gives occasionally personalized advices to users based on the results of energy audits carried out in all homes in the early phase of the project taking into account the technical characteristics of the home (e.g. no air cooling advices are given if the home is not equipped with cooling system). These advices are structured into categories (cleaning, media and entertainment, cooking, etc.). Furthermore, advices are also proposed based on the analysis of the electricity consumption (e.g. important consumption during night leads to advice on lowering stand-by consumption).

- The Apolis Planeta serious game (Fig. 2). This is a game and social network platform where users can play by using creative functions to produce pixel art and share positive actions and projects within a worldwide social network while stimulating the reduction of energy consumption at home. Full functionalities are available for homes equipped with smart meters connected to the system.

Apolis Planeta shifts the boundary between the real and the virtual world as the main objective of the game scenario is to encourage current positive actions based on real life in order to save the world from a virtual disaster in 2050 where all the world is polluted. Therefore, every user has the objective to earn virtual money called Greenies by reducing energy in order to spend them in Apolis Planeta to depollute a zone of the hexagon-squared map of the world by proposing an image, a message or a drawing.

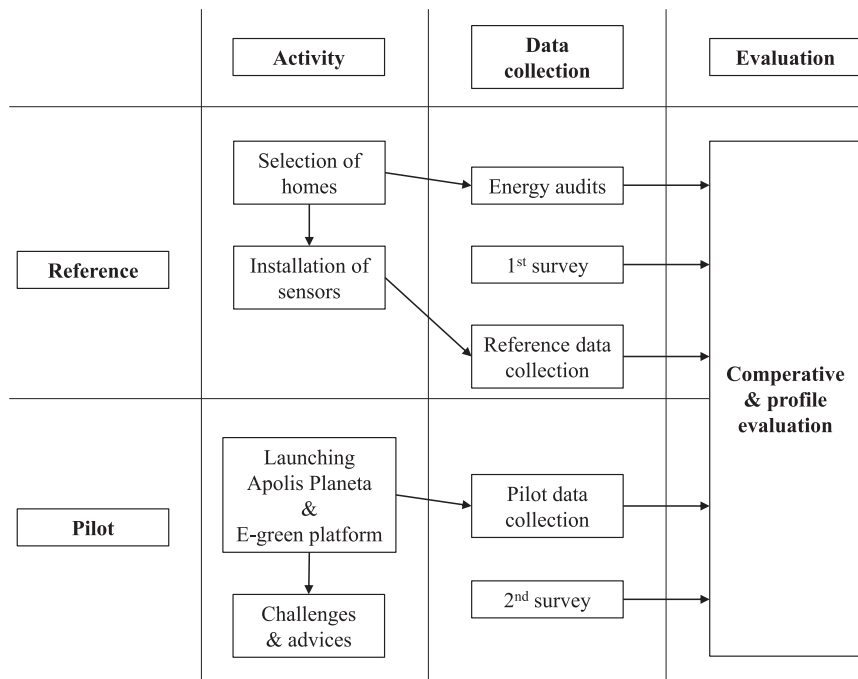


Fig. 1. Concept map of the research.



Fig. 2. Apolis Planeta serious game on mobile application.

Table 3
Number of monitored homes.

Geographical area	Homes with data	High data quality GENERAL	High data quality HEATING	High data quality DHW
Isère (LE COL) SE France	58	19	20	19
Basque Country and the southern Landes (OPAC) SW France	35	11	10	9
VIGO area Spain	64	19	17	14
TOTAL	157	49	47	42

2.4. The homes subject to analysis, data filtering, on-site visits, characteristics of users

Altogether 157 homes were involved in the project from 3 geographic areas (Table 3): the Vigo area, (North-West Spain), the Isere area (South-East France) in cooperation with housing association LE COL and an area in the French Basque country in cooperation

with housing association OPAC. The pilot areas were selected taking into account management and technical aspects. In the project organizations from three countries participated (from France, Spain and Hungary). First it was checked how widespread it was to use electric heating in the countries. In France electric heating is general and finally two areas were selected there. Hungary was excluded due to very low rate of electric heating. Spain was in the

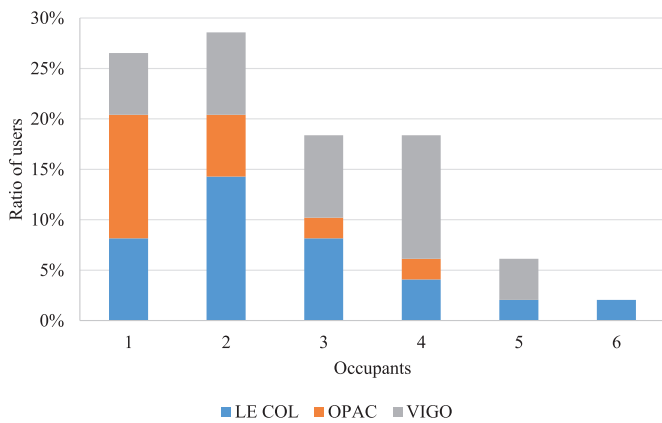


Fig. 3. Distribution of participating homes per number of occupants living in the home.

middle with a moderate, but acceptable rate. Vigo pilot area was selected in the region of project consortium partner Faimevi responsible for communication with pilot homes in Spain. They carried out a door-to-door communication campaign, thus easy reach was an important issue. In France the pilot areas were searched within a tender targeting housing associations all over the country.

Participation was voluntary, but certain technical requirements had to be fulfilled, such as available internet connection and heating and domestic hot water generation had to be based on electricity. Homes were reached through a door-to-door communication campaign in Spain and with the involvement of housing associations in the two French areas. Willingness to play with a video game was not a selection criterion either.

About 45% of the apartments were equipped with controllable electric radiators and nearly 40% had electric boiler with heat storage capacity. Split units were sporadic. In France nearly all apartments had a roomwise programmable thermostat. In Spain roomwise control was also general, but approximately 40% had manual thermostat. In the majority (90%) of the apartments electric water heating in a tank (50–150 l) was installed. Nearly all apartments (90%) had an exhaust ventilation with temporarily operated fans and balanced ventilation with heat recovery was in 2% of the homes only. Household devices and their operation schedules were also investigated.

The monitoring of the energy consumption and indoor air temperature was conducted in the participating homes. The monitoring was running from January 2017 till the end of June 2018. During the project there were homes who backed out or the data collection was temporarily or permanently interrupted (users were able to disconnect the sensors). After closure of the monitoring data collection the data was evaluated and where data quality did not fulfil certain criteria those datasets were excluded from the analysis. The main criteria were as follows:

- General consumption (covering all electric use in the home): more than 85% of daily consumption data available for the period 01.01.2017–30.06.2018
- Heating consumption: more than 80% of weekly consumption data available for weeks 5–22 in 2017 and for the same period in 2018 (for some analysis we considered those homes where more than 85% of daily consumption data was available for the periods 01.01.2017–15.04.2017 and 15.10.2017–15.04.2018)
- DHW (domestic hot water) consumption: more than 85% of daily consumption data available for the period 01.01.2017–30.06.2018

Other criteria were applied as well such as too high heating consumption (more than realistic low power mode consumption)

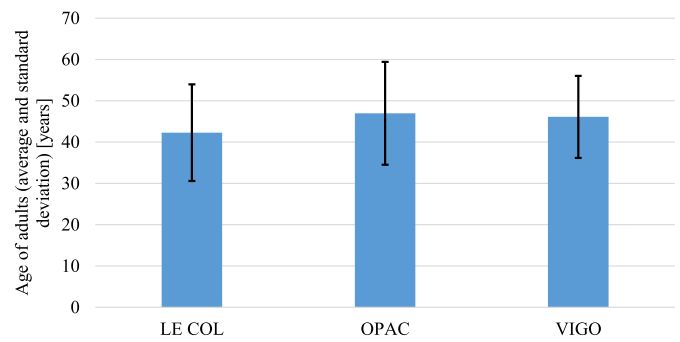


Fig. 4. Distribution of participating homes per average age of adults.

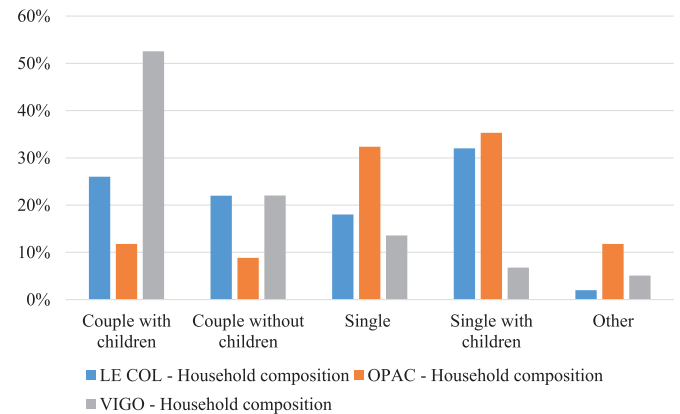


Fig. 5. Household composition of participating homes.

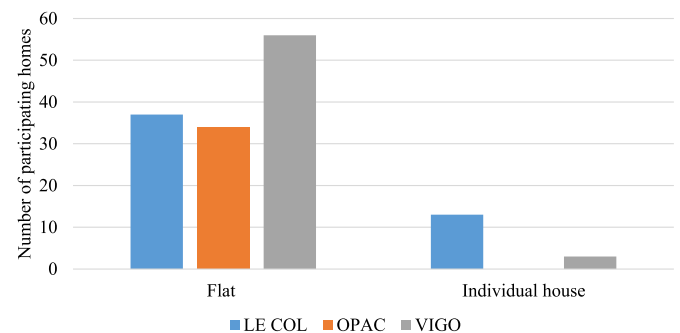


Fig. 6. Distribution of participating homes per type of home.

in summer or the sum of heating and DHW consumption should be lower than general consumption. There were homes where it has turned out that some additional appliances were connected to the heating (or to the DHW) circuit, thus the heating data included the consumption of these additional units as well. It was decided case by case if such datasets were included into the analysis or not depending on the significance of the related error.

The final numbers of homes taken into account in the evaluation are summarized in Table 3.

During the analysis specific consumption values (per m² floor area and per user) have been calculated in order to obtain comparable data. The necessary information was collected during the on-site visits when the sensors were installed. In addition, supplementary technical information about apartment type, building physical parameters, heating system, cooling system, DHW system, cooling system were collected as well. Most apartments were located in multi-family buildings with various years of construction. The majority of the apartments in Spain were heated by electric radiators, in France direct electric air heating was frequent as

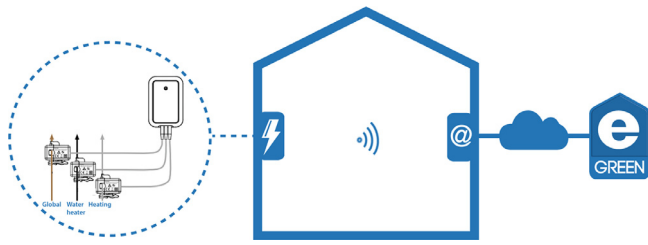


Fig. 7. Monitoring concept and associated internet platform.

well. Heat pumps, cooling systems and mechanical ventilation (except for individual exhaust fans in kitchens, bathrooms and toilets) were exceptional. Nearly all apartments were equipped with electric heated storage tanks.

Characteristics of users were also subject to analysis. Fig. 3 shows the distribution of participating homes per number of occupants for those homes where more than 85% of daily consumption data was available for the period 01.01.2017–30.06.2018. It shows that in VIGO there is a tendency of more families with more occupants, in LE COL there are mainly couples and OPAC there are mainly singles. Certainly, further characteristics were investigated as well such as distribution according to age (Fig. 4), household composition (Fig. 5) or type of the home (Fig. 6). However, analysis of consumption according to sub-categories would have led to too low number of samples per categories, therefore it was decided to distinguish according to pilot area only.

2.5. Data collection

In order to monitor the consumption of the homes and get numeric results about the impact of the experiment, consumption monitoring devices were installed in the participating homes. The applied technology pack included sensors, transmitters and associated internet platform eGreen (Figs. 7 and 8). The devices worked using ammeter clamp sensors, measuring current in the electric cables on the principle of the electromagnetic effect.

Three sensors were installed in the electric panel of each home to monitor the general, the heating and the water-heating consumption. All homes were equipped with electric heating and electric domestic hot water heating devices. A transmitter sent data of consumption to a wireless gateway. This gateway transmitted the information in a secured way to the internet box of the household.

In addition, an indoor air temperature sensor was installed as well to measure thermal comfort of the home.

Consumption data were registered on a private internet platform, reachable through the eGreen website (www.egreen.fr). Each home had access to view its energy consumption, both real time and historical data. Diverse functionalities were proposed by the connected energy-focused serious game (Apolis Planeta) to users to encourage sustainable behaviors, in a social and entertaining way: monitoring of consumption, decrease objectives, comparison with friends or anonymous neighbors results, advices or alerts in case of overconsumption.

2.6. Outdoor temperature data

Measured outdoor temperature data were retrieved from Ogimet Weather Information Service's closest weather station corresponding to each sample home [53]. Both daily and weekly average data were used for different evaluation purposes.

Fig. 9 shows weekly data for the three pilot areas from January 2017 to June 2018. VIGO and OPAC show very similar evolution, due to the similar weather conditions (proximity of the Atlantic coast). LE COL is located in a more continental area and therefore annual amplitude is higher (slightly colder winter, slightly warmer summer). However, in all three areas moderate winter and summer conditions were registered during the monitoring period with (weekly average) temperatures above zero most of the time (Fig. 10).

2.7. Evaluation of energy performance

In order to process monitoring data widely used methods were applied such as energy signature, heating degree days corrections and statistical data processing in accordance with Renz [18] and Woodall [19]. Specific values related to floor area unit, number of occupants or were calculated to make results of the homes with different characteristics comparable. To determine hourly, daily and monthly consumption trends the most illustrative projection base proved to be the average consumption of the relevant period.

2.8. Questionnaires on users' habits

In 2017 before launching Apolis Planeta an online questionnaire on users' habits has been sent out to the homes to obtain a picture



Fig. 8. Integrated concept of the monitoring platform and the serious game.

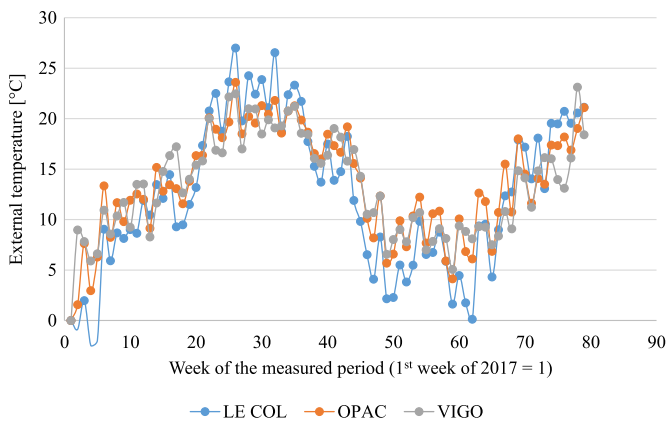


Fig. 9. Weekly average external temperatures during the monitoring period for the three pilot areas.

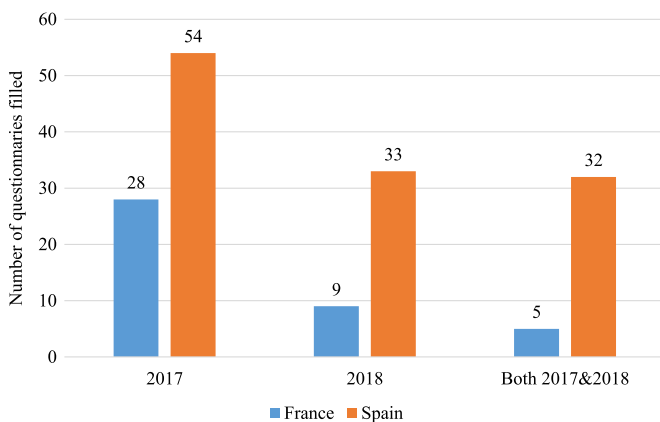


Fig. 10. Number of homes filling the environmental awareness questionnaire in 2017, in 2018 and in both years in the two countries.

about occupants' behavior related to energy awareness. After the closure of the monitoring period a similar questionnaire has been circulated among occupants in July 2018 to see changes in energy awareness. The comparative survey provided information about the users on different aspects such as:

- their level of energy awareness in general,
- apartment characteristics (e.g. existence of cooling devices),
- what occupants believe about their heating, domestic hot water and household appliance using habits that could be compared to the measured results (e.g. operation habits on heating thermostats, bathing / showering frequencies, differences between family members),
- information about the devices they have in the apartment (e.g. energy efficiency level of TVs, washing machines, freezers) and about customs on their usage providing supplementary results to the measurements,
- changes on devices between the pre- and post-evaluation time.

In 2017 we received 28 answers from France and 54 from Spain, however in 2018 only 9 valid questionnaires were submitted by the occupants from France and 33 from Spain in spite of an intensive campaign and the fact that the questionnaire was significantly shortened. Number of homes filling both questionnaires are 5 for France and 32 for Spain. Due to the low number of homes filling both questionnaires in France we excluded the French case from the evaluation.

3. Results and discussion

3.1. Activity of tenants in the pilot period

Occupants started playing Apolis Planeta at the end of 2017. Until June 2018 they were stimulated several times in different ways, such as three contests have been lunched, questionnaires were sent out to get their feedback and telephone campaigns were carried out as a direct stimulus. Fig. 11 presents the stimulating activities and the number of user connections to Apolis Planeta. In spite of the more than 50 communication actions the number of user connections remained moderate particularly in LE COL and OPAC and most of the connections were related to a small number of homes, other homes were permanently inactive. Fig. 12 shows the number of connections per month to the game of the most active players during the playing period.

3.2. Analysis of heating consumption data

Analysis of weekly heating consumption data was carried out for those users where more than 80% of weekly consumption data was available for weeks 5–22 in 2017 and for the same period in 2018. There were 47 homes fulfilling this criterion.

The heating energy consumption of apartments was in the range of 0–72 kWh/m²year. The low figures can be explained by the moderate climate (average outdoor temperature of the heating seasons were in the range of 6.84–10.52 °C).

3.2.1. Heating energy consumption

The performance of individual homes were compared for identical periods in 2017 and 2018 using energy signatures (see Fig. 13 as an example home). Daily heating energy consumptions in function of outdoor air temperature are presented for the two periods (2017: before pilot, 2018: after pilot). As known, heating consumption is strongly influenced by outdoor temperature (trend lines and correlation coefficients are indicated on the figure). In case of energy saving line 2018 (orange) should be under line 2017 (blue) with a lower steepness as the selected example of user 46 shows. For some cases the correlation was low (under 0.5) or very low (around 0.3). It can be explained by other independent variables (other from external temperature) not monitored within the project. The measurements were made mostly in apartments and not in entire buildings. In apartments the influence of the neighbors' heating habits can be very high. The impact of other factors, such as periods of set-back in heating system use or solar gains and wind should not be forgotten either. In season 2018 there were very few days with cold temperatures. In both years there are many days with moderate temperatures (above 10°). In such transition periods, the impact of certain variables such as solar radiation or neighbors' heating habits increase. In case of these occupants it is hard to prove neither energy savings nor its opposite based on the available data, because the correlation was too low. After the analysis of the diagrams one by one it can be concluded that although there were homes with a decreasing trend, in general no consequent change in heating energy consumption can be justified as a result of the gaming activities. The statement is valid even if we focus on active players only. However, as explained before, it does not necessarily mean that users' behavior did not change.

Energy signatures for LE COL homes are presented in Fig. 14 and in Fig. 15. In case of some users it was experienced that there was non-zero energy consumption in summer. These homes are represented in Fig. 15. For most of these homes the summer consumption is constant and very low. It means that the electric heating system was working in low power mode. However, in case of user 23 the summer consumption was significant and not constant. Probably appliances other than heating system are connected to

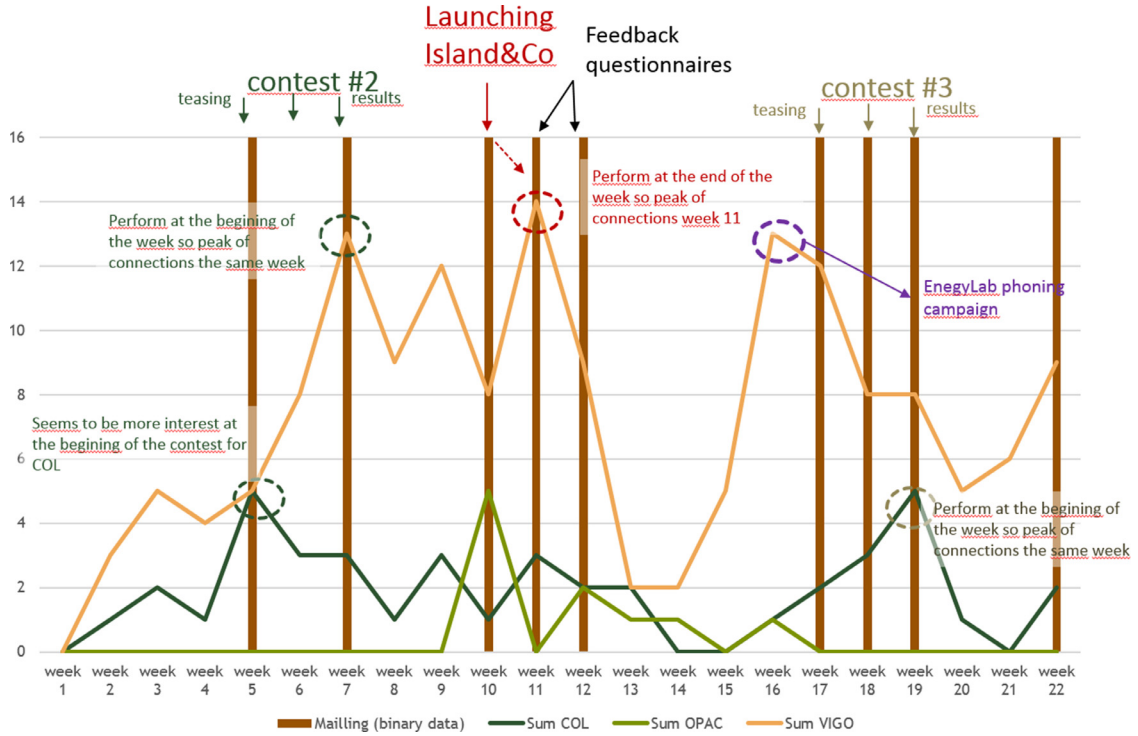


Fig. 11. Activity of homes and milestones of support actions in during the first 22 weeks of 2018.

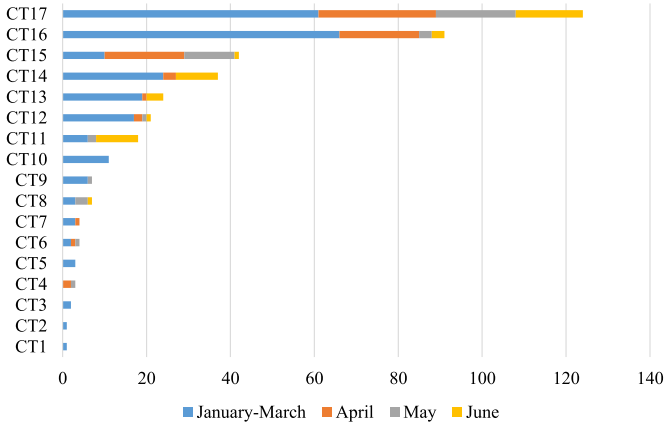


Fig. 12. Monthly number of connections to Apolis Planeta of most active players during first half year of 2018.

the heating circuit here. This home and another similar one from Vigo were excluded from some of the analysis.

Heating energy use before and after launching the game is compared in Fig. 16 for LE COL and in Appendix (Figs. A1 and A2) for the other two sites. In the diagrams the values of the horizontal axis are as follows:

$$\vartheta_{i,2017} - \vartheta_{i,2018} \text{ [}^\circ\text{C]}, \quad (1)$$

where

$\vartheta_{i,2018}$ [°C] - average indoor air temperature of home i during the heating season 2018 (only for weeks 5–22)

$\vartheta_{i,2017}$ [°C] - average indoor air temperature of home i during the heating season 2017 (only for weeks 5–22)

The figures of the vertical axis are as follows:

$$\phi_{2017,i} - \phi''_{2018,i} \left[\frac{\text{kWh}}{\text{week}} \right], \quad (2)$$

where

$\phi''_{2018,i}$ [$\frac{\text{kWh}}{\text{week}}$] - average weekly consumption of home i during the heating season 2018 (only for weeks 5–22) corrected with heating degree days using constant 17 °C indoor air temperature:

$$\phi''_{2018,i} = \phi_{2018,i} \cdot \frac{17 - \vartheta_{e,2017}}{17 - \vartheta_{e,2018}} \left[\frac{\text{kWh}}{\text{week}} \right], \quad (3)$$

where

$\phi_{2018,i}$ [$\frac{\text{kWh}}{\text{week}}$] - average weekly consumption of home i during the heating season 2018 (only for weeks 5–22)

$\vartheta_{e,2018}$ [°C] - average outdoor air temperature during the heating season 2018 (only for weeks 5–22)

$\vartheta_{e,2017}$ [°C] - average outdoor air temperature during the heating season 2017 (only for weeks 5–22)

Weeks with data gaps were excluded from the calculation. With this approach (considering constant indoor temperature in the HDD correction) the consumption values reflect the impact of the change in indoor air temperature. If indoor air temperature decreases the presented consumption should decrease as well (certainly other factors may have a more significant opposite effect). The applied 17 °C was selected because for most users the regression line of energy signatures hits the horizontal axis at this point meaning that above this temperature the heating is not used (in average).

Data points above the horizontal axis mean that consumption was lower in 2018 than in 2017. Regarding the figures it can be remarked that for the majority of users the consumption has increased. However, spots on the right side from the vertical axis mean that users kept higher temperatures in 2017 than in 2018. It can be stated that the majority of the users decreased the indoor temperature. It also means that users made efforts to decrease their consumption, but the consumption has increased. The probable reasons for the increased consumption are the mentioned independent factors rather than indoor air and outdoor air temperatures.

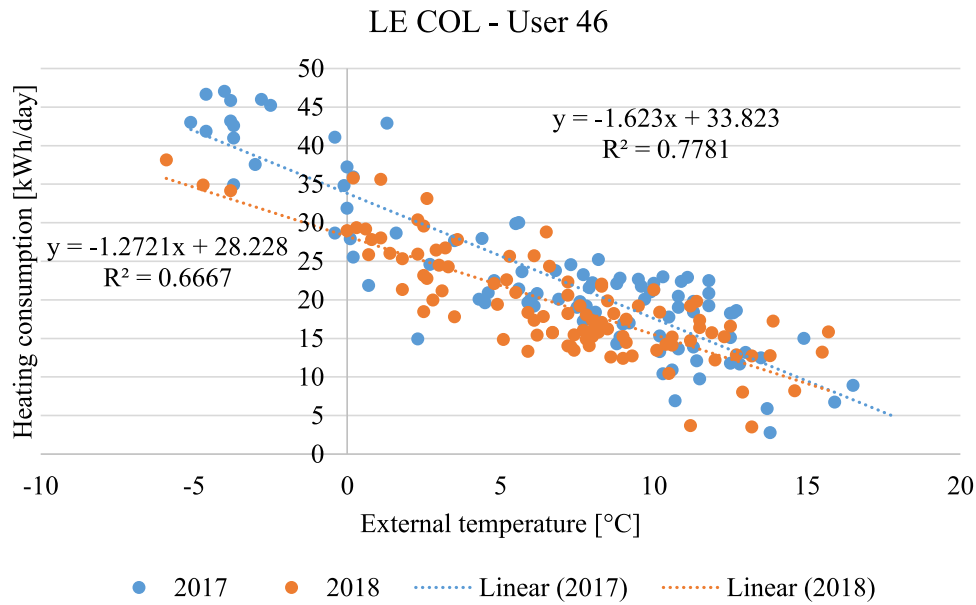


Fig. 13. Comparison of daily heating energy consumption for 2017 and 2018 for user 46 in function of outdoor temperature (example for decrease in energy consumption). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

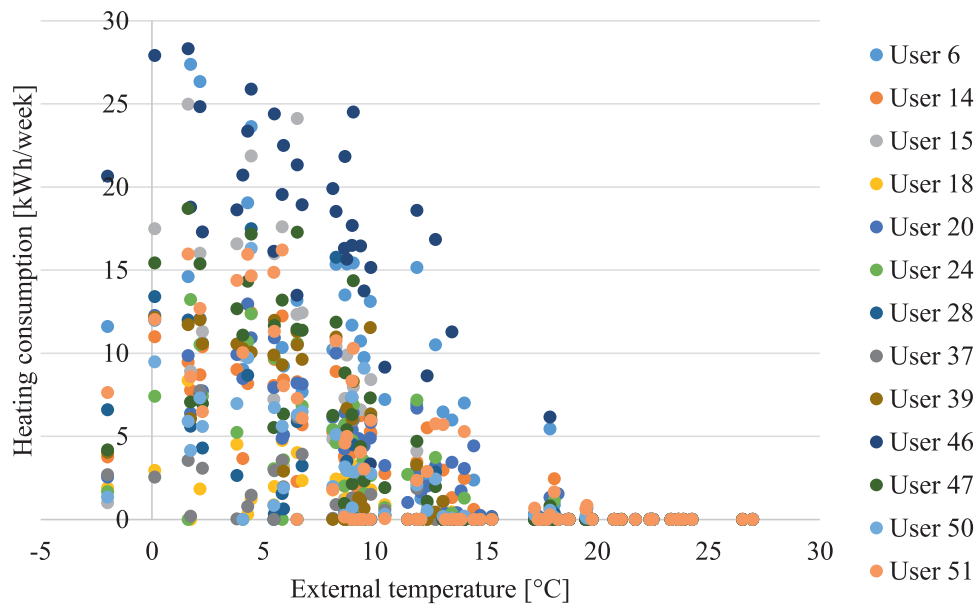


Fig. 14. Energy signature for users with zero heating consumption in summer (12 user – LE COL).

3.2.2. Indoor air temperature during heating season

The previous conclusion of the decreased indoor temperature is well justified by Fig. 17 as well. Spots in the diagram show average indoor temperatures for heating seasons of 2017 and 2018 for individual homes. If a spot is above the 45° line the temperature of the home was higher in 2018 than in 2017, otherwise lower.

Decreasing the indoor temperature is the most important action a user can take in order to lower the heating consumption. To conclude, in spite of the increased consumption we can observe that in average users’ behaviors have improved after the pilot action. The average decrease in indoor air temperature was 0.32 °C for LE COL, 0.18 °C for OPAC and 0.99 °C for Vigo (Table 4). If we exclude the impact of other independent variables it corresponds to a theoretical energy saving of 4.6% for LE COL, 1.9% for OPAC and 10.4% for Vigo (Table 4). These savings were calculated as follows (for

abbreviations see Table 4):

$$\frac{\Delta\phi^*}{\phi_{2017}^*} = \frac{\left(\bar{\vartheta}_{i,2017} - \left(\frac{\bar{\vartheta}_{e,2017} + \bar{\vartheta}_{e,2018}}{2}\right)\right) - \left(\bar{\vartheta}_{i,2018} - \left(\frac{\bar{\vartheta}_{e,2017} + \bar{\vartheta}_{e,2018}}{2}\right)\right)}{\left(\bar{\vartheta}_{i,2017} - \left(\frac{\bar{\vartheta}_{e,2017} + \bar{\vartheta}_{e,2018}}{2}\right)\right)} \cdot 100[\%], \tag{4}$$

The formula excludes the impact of change in external temperature and all other factors. These savings are not reflected by the measured consumption because the impact of other factors independent from project actions is significant.

Fig. 18 compares the evolution of the hourly temperatures in an average day of all analyzed homes for the months February 2017 and February 2018. The night set-back is clearly remarkable such

Table 4
Changes of average temperatures for all homes between the analyzed period of the heating seasons.

	Average indoor temperature			Average external temperature			Savings $\frac{\Delta\phi}{\phi_{2017}} \%$
	2017 $\bar{\vartheta}_{i,2017}$ °C	2018 $\bar{\vartheta}_{i,2018}$ °C	Difference °C	2017 $\bar{\vartheta}_{e,2017}$ °C	2018 $\bar{\vartheta}_{e,2018}$ °C	Difference °C	
LE COL	19.81	19.49	-0.32	7.2	6.84	-0.34	4.6%
OPAC	21.34	21.15	-0.18	9.87	9.48	-0.39	1.9%
VIGO	19.97	18.98	-0.99	10.52	8.56	-1.95	10.4%

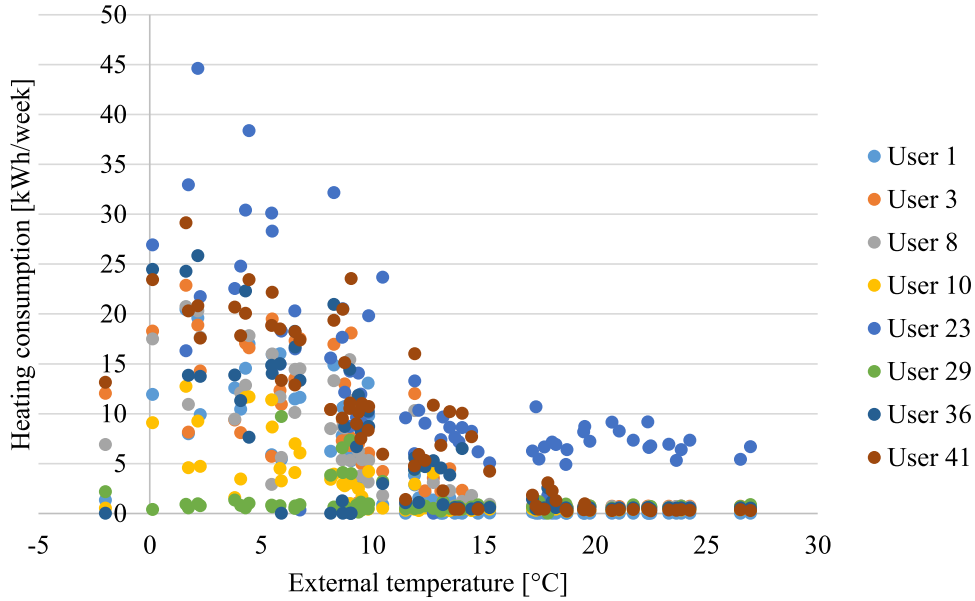


Fig. 15. Energy signature for users with heating consumption in summer (8 user – LE COL).

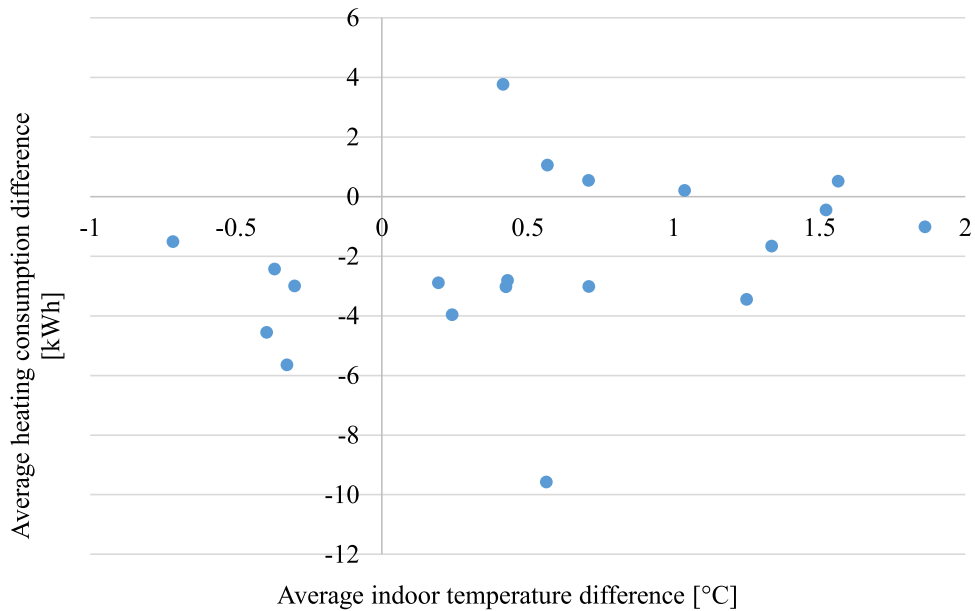


Fig. 16. Difference of average weekly energy consumption between 2017 and 2018 in function of indoor temperature difference between 2017 and 2018 (LE COL) – HDD correction with 17 °C indoor temperature.

as the decreased indoor air temperature after introducing the serious game.

3.3. Domestic hot water (DHW) consumption

The analysis of DHW consumption data was carried out for those homes where more than 85% of daily consumption data was

available for the period 01.01.2017–30.06.2018 (LE COL: 19 homes, OPAC: 9 homes, VIGO: 14 homes). Altogether 42 homes were analyzed.

3.3.1. DHW consumption profiles

Annual specific DHW heat consumption for the selected 42 homes are presented in Fig. 19 in function of floor area. The

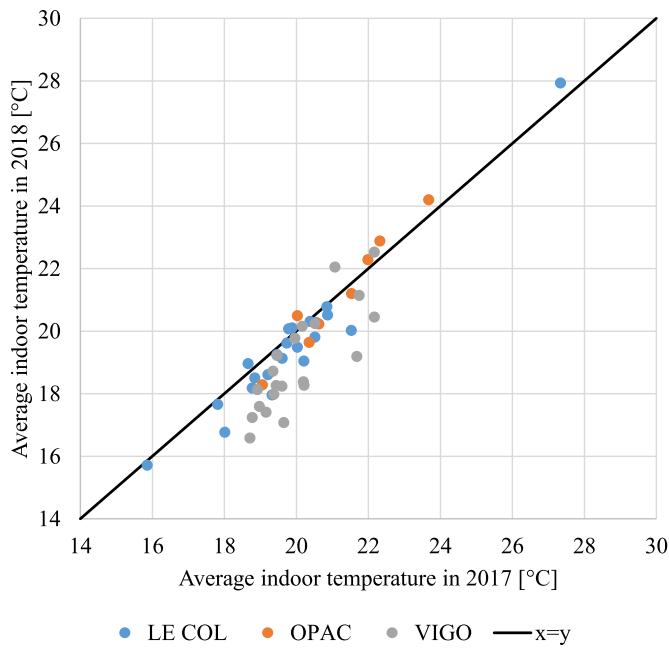


Fig. 17. Average indoor temperatures in the heating seasons of 2017 and 2018 for different homes.

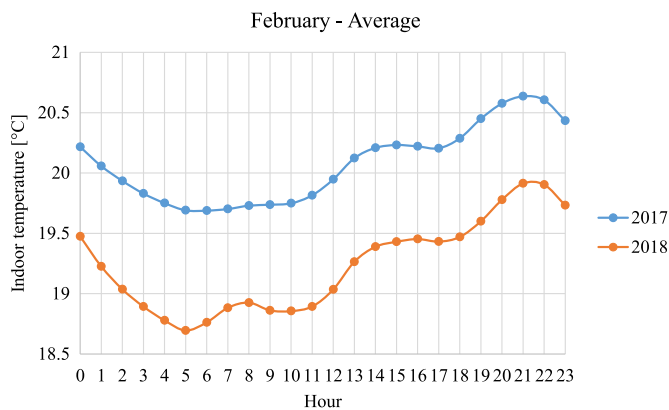


Fig. 18. Daily average trend of hourly indoor temperatures in February 2017 and 2018 in the analyzed homes.

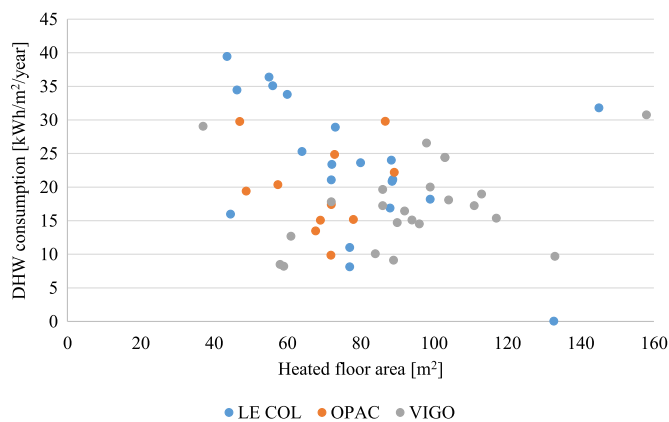


Fig. 19. Annual specific DHW heat consumption related to floor area (entire year 2017) for different homes.

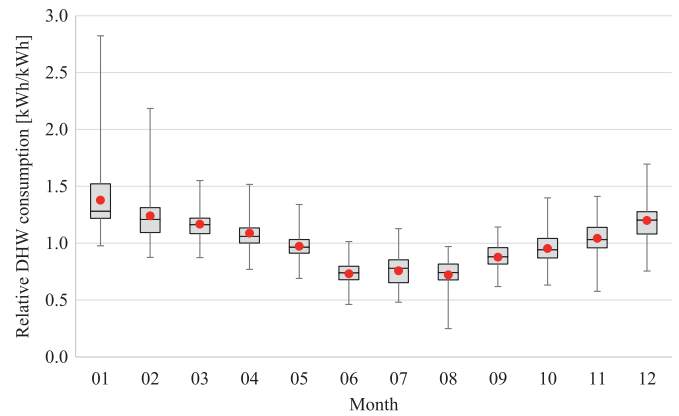


Fig. 20. Average daily DHW heat consumptions per month related to annual average of daily DHW heat consumption for different homes (incl. all three pilot areas).

specific DHW consumptions of apartments were in the range of 0–40 kWh/m²year. The trend is slightly decreasing as a larger apartment does not necessary correspond to more occupants and DHW consumption strongly correlates with the number of occupants. Average values for the three pilot areas and for all 42 homes are in Table 5. The corresponding domestic hot water demand is estimated as well assuming 15 °C cold, 50 °C domestic hot water temperatures. The values are given for two cases: for assumed system efficiency of 100% and 90%. The annual total and specific consumption related to occupant number and related to floor area are presented in further diagrams in the Appendix (Figs. A3–A5).

Variations of daily consumptions of a home during a year or a week or any time period can be interpreted in an illustrative way by comparing its daily values to its annual average consumption. In Fig. 20 daily consumptions are compared to annual average on a monthly basis (see also other representations of the results in Figs. A6–A8 in Appendix). Values above 1 mean higher, below 1 mean a lower monthly average daily consumption than the annual daily average. The highest consumptions are in the winter period, the lowest ones in the summer. Red spots show average consumption of all selected homes. The lowest consumption in June is nearly the half (53%) of that in January. Between winter and summer there is a monotonously increasing trend and the opposite in autumn. The significant difference can be explained by a synergic impact of several reasons:

- lower water consumption in summer due to shorter showers (for comfort reasons) and vacations,
- lower domestic hot water temperature set in summer for comfort reasons (in winter people prefer higher water temperatures),
- higher cold water temperature in summer than in winter due to annual variation of soil temperature surrounding utility supply pipes,
- lower distribution and storage heat losses in summer than in winter due to the lower temperature difference between domestic hot water temperature and environmental temperature.

The higher consumption in colder weather is also illustrated by Fig. 21 (see also Figs. A9 and A10 in Appendix). The correlation coefficient is around 0.5 meaning a moderate, but clearly remarkable relationship.

As the Fig. 20 shows the monthly relative consumptions of October, November, April and May are very close to 1. It means that annual consumptions can be easily estimated from the consumptions of these months. Since heating is usually turned off in May the consumption of May can be a good calculation basis for annual DHW consumption even if DHW and heating is not measured

Table 5
Annual specific DHW heat consumption related to floor area (entire year 2017) – average for all selected homes.

	Annual DHW consumption per floor area [kWh/m ² year]	Annual DHW consumption per occupant [kWh/occupant, year]	Estimated average daily DHW consumption [liter/occupant] 100% system efficiency	Estimated average daily DHW consumption [liter/occupant] 90% system efficiency
LE COL	20.89	842	56.7	51.0
OPAC	19.71	874	58.8	53.0
VIGO	17.77	591	39.8	35.8
All areas	20.10	742	49.9	44.9

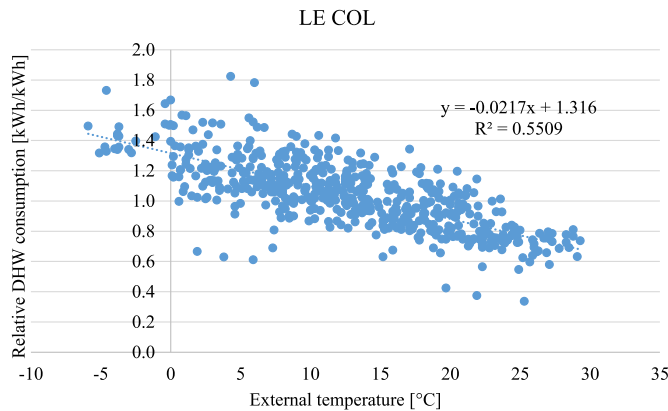


Fig. 21. Daily DHW heat consumptions of the average home in LE COL area in function of external temperature.

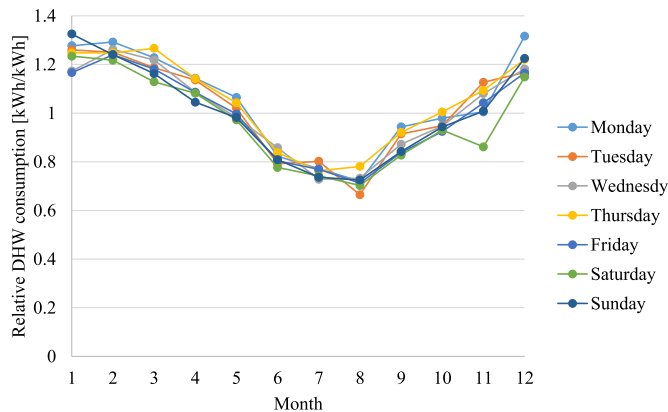


Fig. 22. Average daily DHW heat consumptions (for different days of the week) per month related to annual average of daily DHW heat consumption for different homes (incl. all three pilot areas).

separately. With other words it is a more accurate approach to use the consumption of May than using summer consumptions which is the current practice.

Fig. 22 presents the variations of daily consumptions during an average week of the month for the different months. The consumption variations between different days of the week are not significant and do not follow the same trend in the different months. No significant difference can be detected between weekdays and weekends, either.

It is also interesting to analyse the daily hourly consumption trends in an average day. Fig. 23 shows the average trends for the average day of February, April and June in 2017 and 2018 (average of all analyzed homes). It should be noted that nearly all homes are equipped by DHW storage tanks with electric heating. The trends show the heat production and not the energy use. Heat production is intensive after the tank is discharged, so peaks in water demand should be before peaks in heat generation: in the

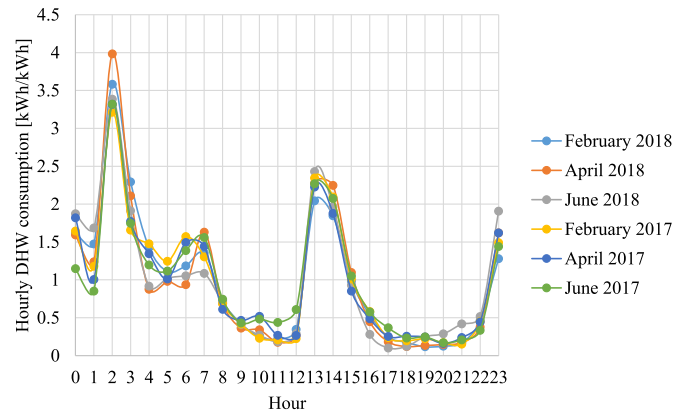


Fig. 23. Hourly average DHW heat consumption on a relative scale (related to the average hourly consumption of the month) in an average day of 3–3 representative months of 2017 and 2018 for different homes.

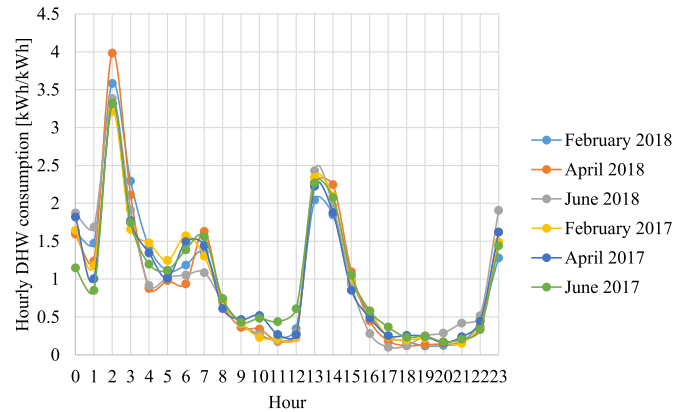


Fig. 24. Average DHW heat consumption in 2017 and in 2018 for different homes.

evening and in the morning hours as expected from the practice. Certainly, off-peak electricity schedule may also play a role. It is also to be recognized that although the daily consumption depends on the month, the hourly trends of a day are nearly the same in the different months of the year. The daily consumption peaks are around 1.00 pm and 2.00 am when off-peak tariffs are applied and it is much higher than the nearly zero minimum consumption between 5.00 and 9.00 pm.

3.3.2. Domestic hot water (DHW) savings

Fig. 24 compares DHW consumptions of periods January 2017–June 2017 and January 2018 – June 2018 for each home. If a spot is above the 45° line the consumption of the home was higher in 2018 than in 2017. In average no notable decreasing or increasing trend can be remarked, the situation is similar before and after pilot action. Certainly some of the users' consumption has decreased, others' consumption has increased, but it would be so without any intervention.

Table 6

Annual specific other electric consumption and average load related to floor area (entire year 2017) – average for all analyzed homes.

	Annual other electric consumption per floor area [kWh/m ² year]	Annual other electric consumption per occupant [kWh/occupant, year]	Annual average other electric load [W/m ²]
LE COL	53.86	1806	6.15
OPAC	28.04	1437	3.20
VIGO	24.06	836	2.75
All areas	36.68	1318	4.19

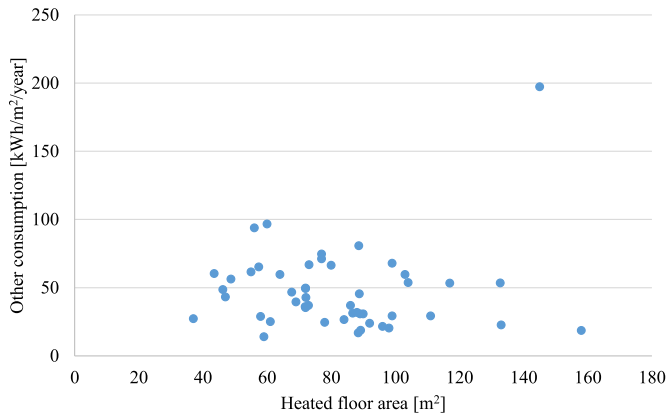


Fig. 25. Annual specific other electric energy consumption of all evaluated homes in function of heated floor area.

3.4. Other electric consumption

Analysis of general (total) consumption data was carried out for those users where more than 85% of daily consumption data was available for the period 01.01.2017–30.06.2018 (LE COL: 19 homes, OPAC: 11 homes, VIGO: 19 homes). Altogether 49 homes were analyzed.

Periodic (annual) consumptions were calculated from the average of daily consumptions of days with valid data. The general consumption of apartments was in the range of 59–158 kWh/m²year with one outstanding value of 268 kWh/m²year.

Other consumption means consumption of all electric devices used in the home excluding heating and DHW production. It was determined as the difference of measured general consumption and heating+DHW consumption.

3.4.1. Other electric consumption profiles

Other electric consumption was in the range of 59–97 kWh/m²year with one outstanding value of 197 kWh/m²year (Fig. 25). A decreasing trend can be recognized with slight correlation with floor area, because a part of the consumption is not necessarily proportional with the size of the apartment (e.g. usually one fridge is enough even in a large apartment).

Average consumption values for the three pilot areas and for all 49 homes are in Table 6. In addition to the annual consumption the table gives average electric loads that can be taken into consideration in energy performance calculations as a part of the internal heat loads.

Other electric consumption results show similar characteristics as domestic hot water consumption. In Fig. 26 daily consumptions are compared to annual average on a monthly basis (see also other representations of the results in Figs. A11 and A12 in Appendix). Similarly to DHW, the highest consumptions are in the winter period, the lowest ones in summer. The lowest consumption in June is less than the half (47%) of that in January. Between winter and summer there is a monotonously increasing trend and the oppo-

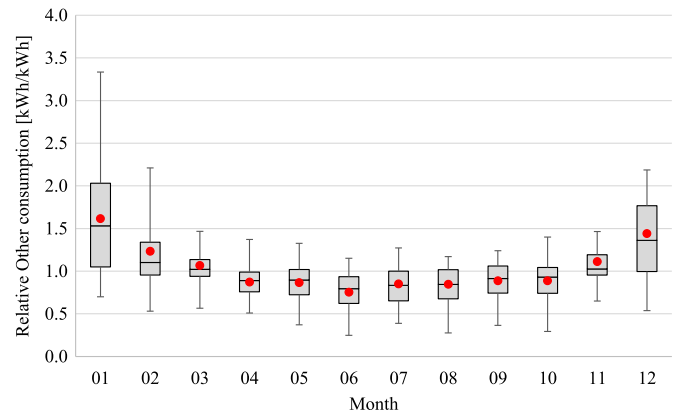


Fig. 26. Average daily other electric consumptions per month related to annual average of daily consumption for different homes (incl. all three pilot areas).

site in autumn. The significant difference can be explained by a synergic impact of several reasons:

- longer daily demand for artificial lighting in winter,
- less time spent outside in winter than in summer and thus more frequent use of entertaining devices (e.g. TV, tablet),
- different cooking habits between summer and winter,
- different washing, ironing and mechanical drying habits (less clothes) in summer and winter,
- further devices used in winter conditions more frequently or exclusively (e.g. air humidifier device, hair dryer)
- in the majority of the apartments there was no mechanical cooling that could increase consumption in summer.

As the Fig. 20 shows the monthly relative consumptions of November and March are very close to 1. It means that annual consumptions can be easily estimated from the consumptions of these months.

The hourly consumption trend in an average day is also worth discussing. Fig. 27 shows the average trends for the average day of February, April and June in 2017 and 2018 (average of all analyzed homes). It can be recognized that although the daily consumption depends on the month, the hourly trends of a day are nearly the same in the different months of the year. The daily peak consumption is at 7.00 p.m. and it is twice as high as the minimum consumption at 2.00 a.m.

3.4.2. Other electric consumption savings

Fig. 28 compares other electric consumptions of periods January 2017 – June 2017 and January 2018 – June 2018 for each home (excluding outstanding values for a better representation). If a spot is above the 45° line the consumption of the home was higher in 2018 than in 2017. In average no notable decreasing or increasing trend can be remarked, the situation is similar before and after pilot action. Certainly some of the users' consumption has decreased, others' consumption has increased, but it would be like that without any intervention.

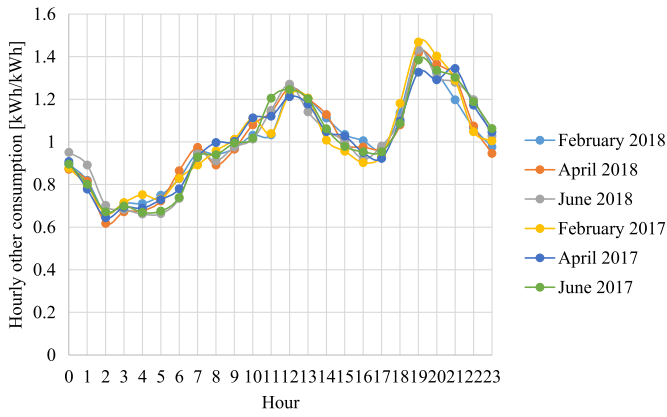


Fig. 27. Hourly average other electric consumptions on a relative scale (related to the average hourly consumption of the month) in an average day of 3–3 representative months of 2017 and 2018 for different homes.

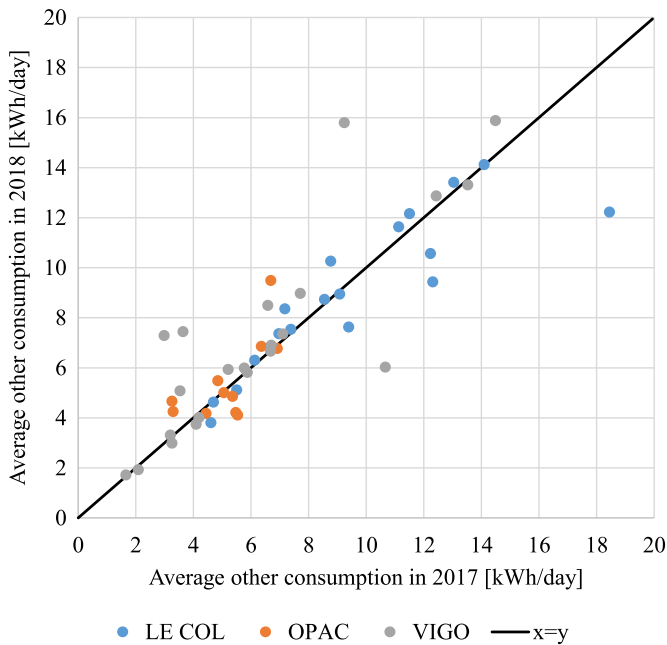


Fig. 28. Average other electric consumption in 2017 and in 2018 for different homes.

3.5. Environmental awareness survey results

In the questionnaire occupants were asked about the indoor air temperature during the heating season. The results showed a rather high level of energy awareness in this issue already in 2017, almost 70% of tenants thought they keep the temperature below 20° or even lower. 28% (Spain) and 43% (France) said that the temperature was between 17 and 19°. These statements were justified by the monitoring data of indoor temperatures (see Fig. 17).

In the followings, statements are based on the survey carried out in Spain, because as explained before, too small number of occupants filled the questionnaire in France. Fig. 29 provides information about heating control habits: 73% of the homes have and regularly use a thermostat for heating setting different temperature for day and night. These users are able to save energy by setting the temperature. As explained in chapter 3.2 some temperature decrease was experienced as a result of the pilot action thanks to these occupants. A smaller group of the homes (18%) do have a thermostat but do not use it and a minority doesn't have or does not know if they have a thermostat or not (9%).

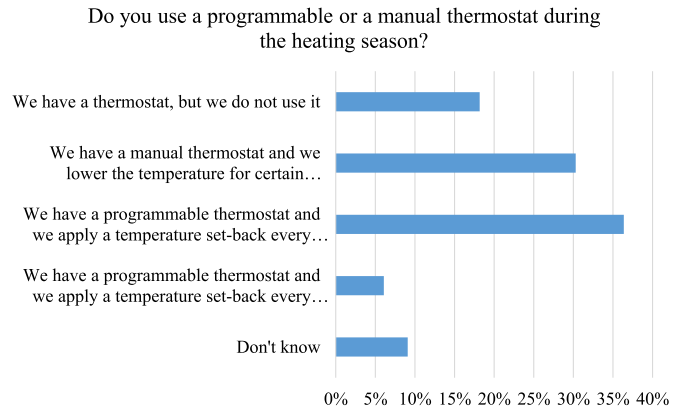


Fig. 29. Results of the questionnaire, 2018.

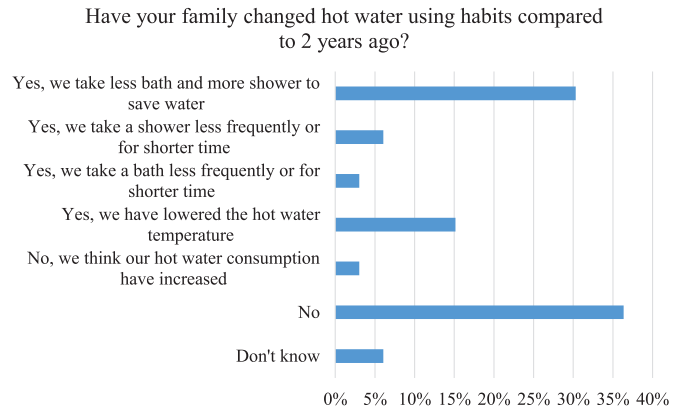


Fig. 30. Results of the questionnaire, 2018.

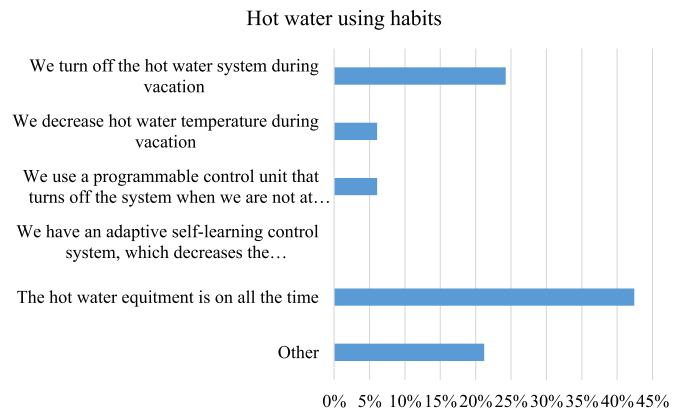


Fig. 31. Results of the questionnaire, 2018.

About domestic hot water using habits significant changes can be reported based on the survey: 54% of the homes claimed to have changed their habits in a positive way and only 3% of Spanish users think that their consumption has increased. In most cases they rather take a shower than a bath and 15% of the homes set domestic hot water temperature lower than earlier (Fig. 30).

In vacation periods the picture is also slightly better. One third of the homes did not do anything about the domestic hot water system when going to vacation in 2017. In 2018 the share was 42%. More people said to turn off the domestic hot water system in 2018 than in 2017 (Fig. 31).

Another positive change is the increased proportion of appliances with energy class A or better. In 2017 it was 41% only, in 2018 it increased to 64%. When buying a new appliance, 97% would

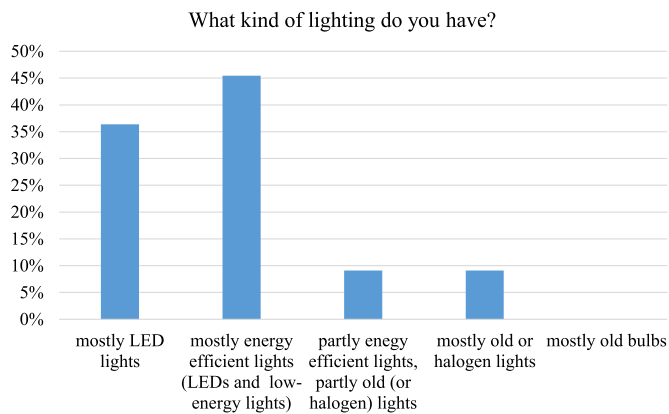


Fig. 32. Results of the questionnaire, 2018.

buy a class A or better unit (93% in 2017). (Figs. A13 and A14 in Appendix)

Many occupants learned the importance of hidden consumption because more occupants knew what hidden consumption means in 2018 than before (74% in 2017, 88% in 2018; Fig. A15 in Appendix). Majority of occupants make efforts to reduce hidden consumption (61% in 2018; 39% in 2017; Fig. A16 in Appendix).

There is a clear improvement in case of lighting systems. In 2017 only 60% of interviewed homes had efficient lighting from that 30% was LED. In 2018 the numbers increased to 81% and 36% (Fig. 32).

To conclude, the energy awareness surveys show certain improvement in most areas even if analysis of monitored data could not always justify all impact of behavioral changes.

4. Conclusion

The first objective of the research was to analyze the energy consumption habits and trends of occupants in nearly 50 homes in France and Spain. The second objective was to determine the impact on energy consumption of a serious game developed within the Horizon 2020 Greenplay project. The main findings on consumption habits and trends can be summed up as follows:

- Monitoring indoor temperature is a simpler, more cost effective and from certain aspects more reliable way to analyze behavioral change with regard to the use of heating systems than monitoring energy consumption although it doesn't reflect all behavioral aspects.
- Annual specific average consumption figures have been determined for DHW and for other electric consumption per floor area unit and per occupants' number. Mean values for internal heat loads related to other electricity were also determined. These results can give a contribution to current knowledge for energy performance calculations and consumption projections. Such values are available from previous research works, but not for these regions and not for 2017–18. As consumption habits are quickly changing during the years, up-to-date results have a significant importance.
- Annual domestic hot water and other electric energy consumption trends have been determined and it was proven that consumption is approximately twice as high in January than during the summer months for both consumption types. In addition, it has been found that annual consumption figures can be easily estimated from the monthly consumption values of October, November, April or May for DHW and that of November or March for other electricity.

- The impact of occupants' number on the DHW and other electric consumptions have been analyzed and numeric results have been elaborated (in Appendix only).
- It has been justified that there is no significant difference between the daily DHW consumption of the homes during the week, even between weekdays and weekends.
- Hourly trends of DHW and other electric consumptions have been determined during an average day and trends (shapes of the curves) proved to be nearly the same in the different months of the year.

With regards to the second objective of the work we can conclude that saving energy with a serious game initiating behavioral change could not be achieved and justified, but some positive elements could be found. Although no energy saving could be detected in heating energy consumption in absolute terms, it was proven that users have decreased their indoor air temperature during heating season showing that they made the necessary effort on behavioral side. The decreased temperatures correspond to a theoretical energy savings 4.6% for LE COL, 1.9% for OPAC and 10.4% for Vigo. In spite of that, the mean heating energy consumption did not decrease. It can be explained by the impact of independent variables other than occupants' behavior (such as heat flow from/to neighboring apartments or changes in meteorological factors other than temperature, like wind, solar yield, etc.) that could not be monitored within the scope of the research.

In domestic hot water consumption no notable decreasing or increasing trend could be recognized, the situation was similar before and after starting the pilot action. Certainly some of the users' consumption has decreased, others' consumption has increased, but it would have been so without any intervention. However, in the survey, 54% of homes claimed that they have changed their DHW using habits in a positive way and only 3% of the occupants thought that their consumption had increased. In most cases they take more often a shower than a bath compared to the situation before the pilot action. Furthermore, 15% of the homes claimed that they had set lower domestic hot water temperatures than earlier.

With regards to other electric consumption no notable decreasing or increasing trend could be detected either, the situation was similar before and after starting the pilot action. However, the survey showed some important behavioral improvements particularly for homes. One positive change to mention is the increased proportion of appliances with energy class A or better. In 2017 it was 41% only, in 2018 it increased to 64%. When buying a new appliance, 97% would buy a class A or better device, 4% more than in 2017.

There is a clear improvement in case of lighting systems. In 2017 only 60% of the homes had efficient lighting, and from that 30% was LED. In 2018 the numbers increased to 81% and 36%.

The mentioned positive impacts can only partly be explained by the use of Apolis Planeta as the number of connections to the game was fairly moderate and most of the connections were associated to a low number of homes. Probably the use of E-Green platform, the regular communication with the dwellers and the fact of being monitored and interviewed also had certain influence on the consumption. It is not possible to clearly separate the impact of these factors, but we made an attempt. From the most active 17 homes a core team has been established and these homes became subject to a further analysis. In spite of some difficulties it was clearly proven that there is a notable energy saving for the majority of the core team homes in other electric consumption. In domestic hot water consumption savings could not be justified because of the too high influence of other independent factors.

5. Recommendations

The following recommendations are based on the lessons learned during project implementation and are addressed for the next research and demonstration projects concerning energy reduction involving behavior-influencing experimentations with households.

5.1. Recommendations concerning households recruitment phase

During the project we noticed that the user's identification and recruitment phases are very important for the results of the experimentation. In our case, we performed the user's recruitment phase using 2 different approaches in France and Spain in order to find people interested to be involved in our experimentation:

We used a bottom up approach (lead by one of the Spanish partner of the consortium) that had made large public dissemination at the beginning of the project: flyer distribution in supermarkets, door to door campaign, presentation to neighborhood associations and schools and media dissemination on public totems and bus stations.

We also used a more "top down approach" especially in France where the recruitment phase was mainly performed by 2 social lessors (involved as subcontractors). They were in charge to communicate and propose to their home occupants to be involved in the experimentation.

Regarding the results of the experimentation, we noticed that the users recruited from the bottom up approach were more empowered and engaged in the experimentation. At the opposite, some French users (involved by the social lessors) had appeared to be not interested or sometimes not really aware of the experimentation and few of them were even edgy. We think that this situation came from the fact that the relation between social lessors and their tenants is not neutral and objective and can change or jeopardize the implication of the users in the experimentation.

We recommend to use a bottom up approach for the recruitment of users and volunteers in this type of experimentation and not involved social lessors as subcontractors. However, both approaches can be very time consuming, the selection of users and the installation of the sensors in the selected homes can take more than one year. Considering that at the monitoring phase it is recommended to take at least two entire years it means that the whole research should be planned for minimum 3.5–4 years.

5.2. Recommendation concerning the creation of a core users test group

In order to foster an agile process, during the recruitment phase, it is recommended to identify and select a restricted core user test group in order to proceed to the beta tests without involving all the others users. These specific users will be selected (approximately 10% of all the users) regarding their profile of early adopters, ability to provide feedback, and tolerance to accept minor or major bugs concerning the development of the system.

5.3. Recommendation concerning the number of users to involved in the experimentation

In case of installation of hardware or software for the experimentation involving users, we recommend to anticipate the number of disclaimer or detraction of users due to move in homes, technical compatibility issues.. In our case, during the GreenPlay experience, only 50% of the 150 equipped users were able to take part into the whole experimentation.

5.4. Recommendation concerning the time and resources for the communication actions with the users

During the design of the new system and its experimentation, the communication with the different users based on the monitoring and the day-to-day analysis of the users' behavior is essential but very time-consuming. We recommend to adapt the effort according to an agile process in order to take into account of the diversity of the users' profile and expectations.

It is recommended to adapt the effort and the communication by framing the sample of users and divide them into different group categories according to their interactions with the proposed solution. For example, during the GreenPlay experimentation we tried to have a dynamic ranking of users in different category: advanced user group, early majority, late majority and non-engaged users.

5.5. Recommendations concerning monitoring of energy consumption

In case of apartments the impact of factors other than outdoor temperature and occupants' behavior (such as heat flow from/to neighboring apartments or changes in meteorological factors other than temperature like wind, solar yield, etc.) are significant that could not be monitored within the frame of the project. We do not think it would be reasonable to monitor all such parameters in another similar project, but we recommend to ensure the monitoring periods before and after the action to minimum 1–1 whole year (ideally we would recommend 3–3 years). Control and maintenance of monitoring sensors during the experimentation is also an important, but resource consuming and sensitive issue as such external interactions might have a negative effect of occupants' willingness on participation.

5.6. Recommendation concerning the platform configuration

If the objective of the project is to use a gamification solution to stimulate users' behavior, we recommend to develop an open solution (instead of proprietary one) in order to invite other stakeholders to develop new propositions (others games, sensors..) that could be connected to the developed solution. It was noticed that it is difficult to design a unique game or gamification solution to fit with the diversity of profiles (parents, children and elderly people). So it is better to provide a range of games to fit with these different publics.

Acknowledgments

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Results and the determined trends are being fine-tuned and extended for other building types with a geographic scope of Hungary in another research project entitled "Large Scale Smart Meter Data Assessment for Energy Benchmarking and Occupant Behavior Profile Development of Building Clusters". Furthermore, methods and approaches developed in the current work are being further developed for large scale data analysis. The project (no. [K 128199](#)) has been implemented with the support provided from the [National Research, Development and Innovation Fund of Hungary](#), financed under the [K_18](#) funding scheme.

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Appendix

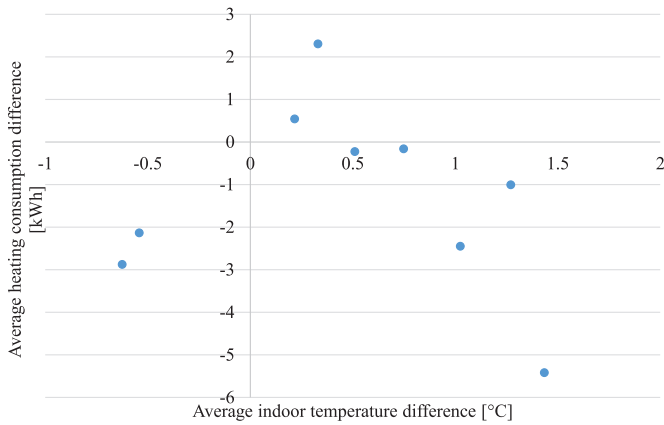


Fig. A1. Difference of average weekly energy consumption between 2017 and 2018 in function of indoor temperature difference between 2017 and 2018 (OPAC).

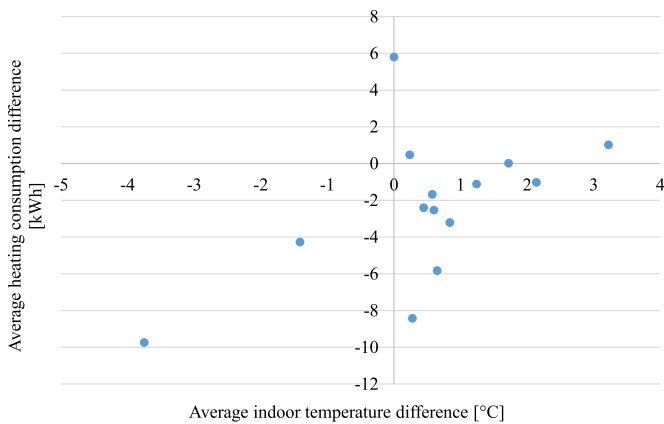


Fig. A2. Difference of average weekly energy consumption between 2017 and 2018 in function of indoor temperature difference between 2017 and 2018 (LE COL).

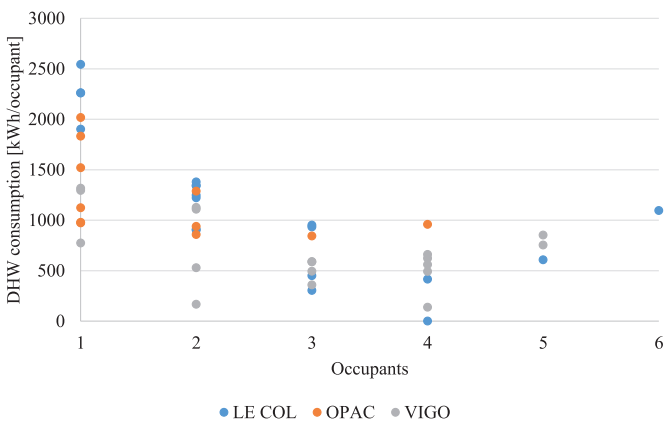


Fig. A3. Annual DHW heat consumption per number of occupants (entire year 2017) for different homes (incl. all three pilot areas).

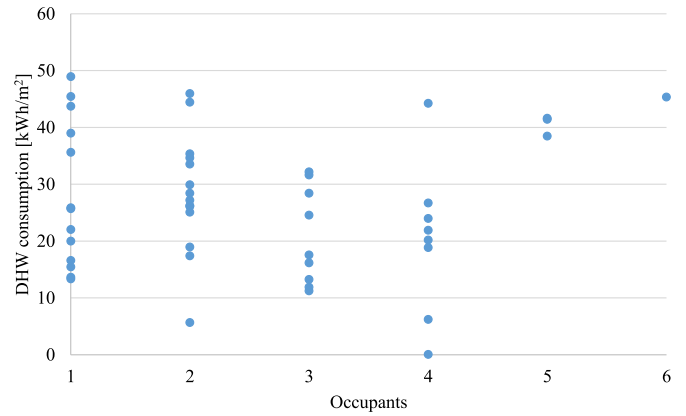


Fig. A4. Annual DHW heat consumption per m² floor area and number of occupants (entire year 2017) for different homes (incl. all three pilot areas).

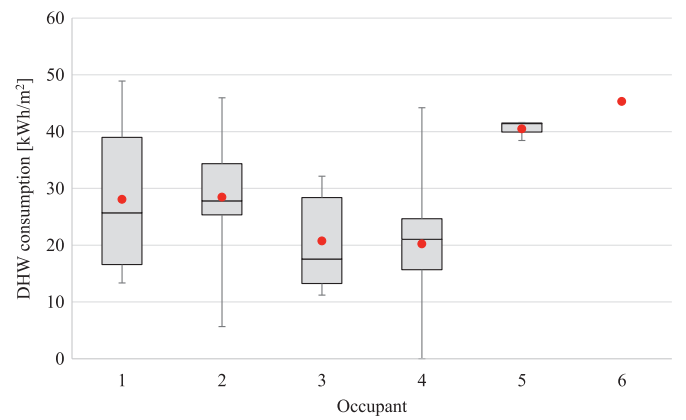


Fig. A5. Annual DHW heat consumption per m² floor area in function of occupants' number (entire year 2017) for different homes (incl. all three pilot areas).

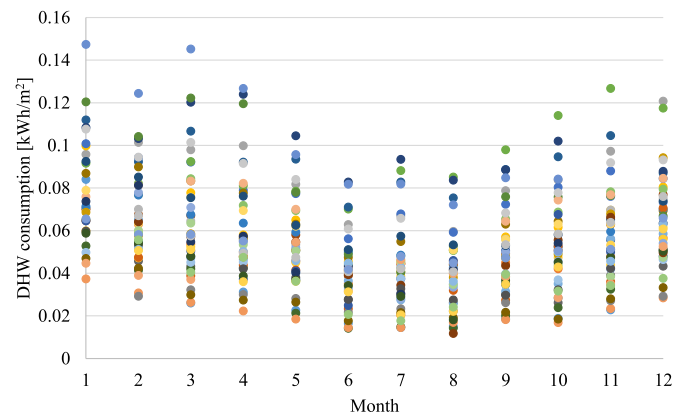


Fig. A6. Average daily specific DHW heat consumptions per month during 2017 for different homes (incl. all three pilot areas).

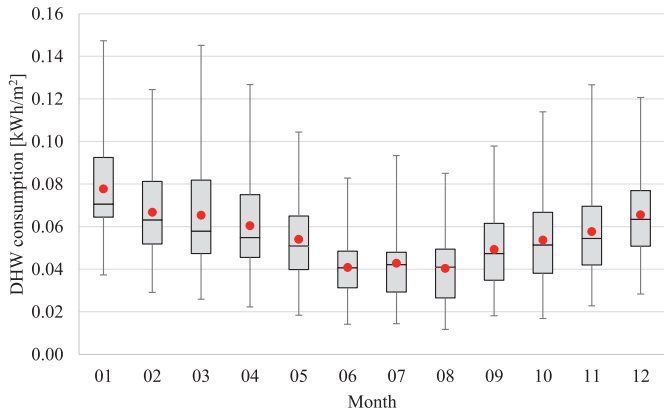


Fig. A7. Average daily specific DHW heat consumptions per month during 2017 for different homes (related to floor area unit - incl. all three pilot areas). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

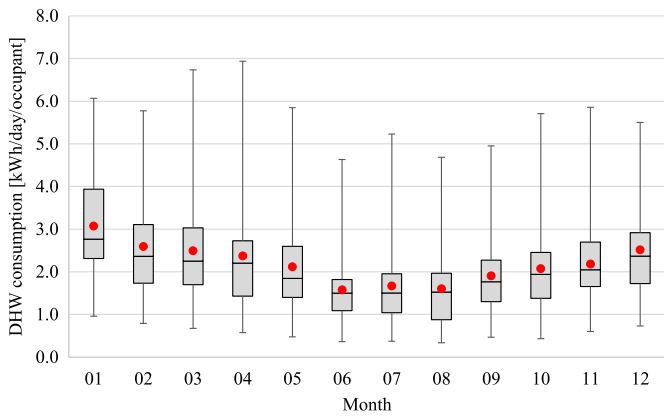


Fig. A8. Average daily specific DHW heat consumptions per month related to number of occupants during 2017 for different homes (incl. all three pilot areas). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

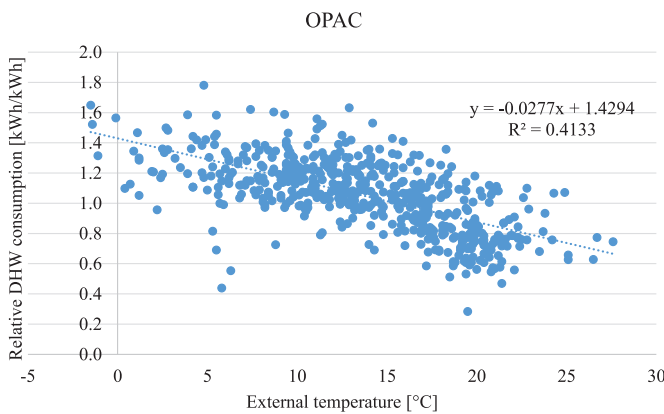


Fig. A9. Daily DHW heat consumptions of the average home in OPAC area in function of external temperature.

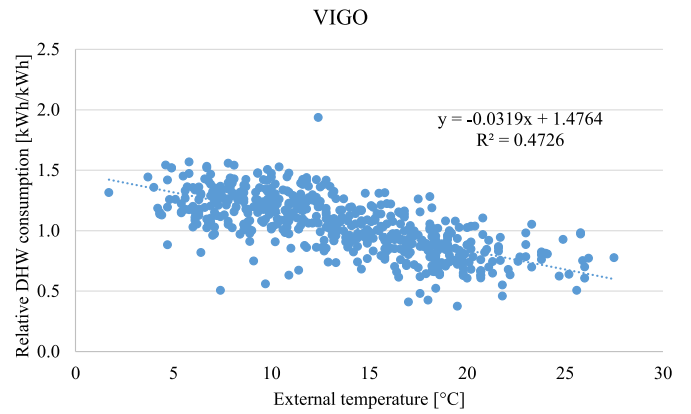


Fig. A10. Daily DHW heat consumptions of the average home in VIGO area in function of external temperature.

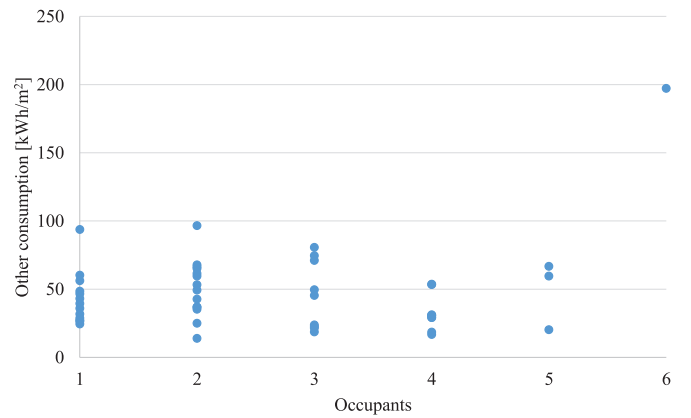


Fig. A11. Other annual electric consumption per floor area in function of occupants' number in the homes (incl. all evaluated homes).

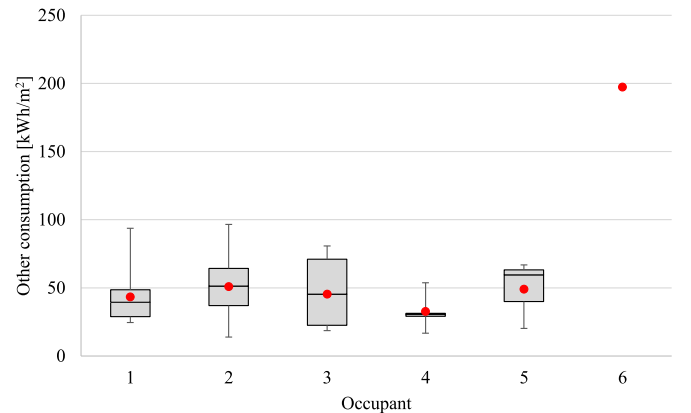


Fig. A12. Other annual electric consumption per occupant and floor area in function of number of occupants in the home (incl. all evaluated homes).

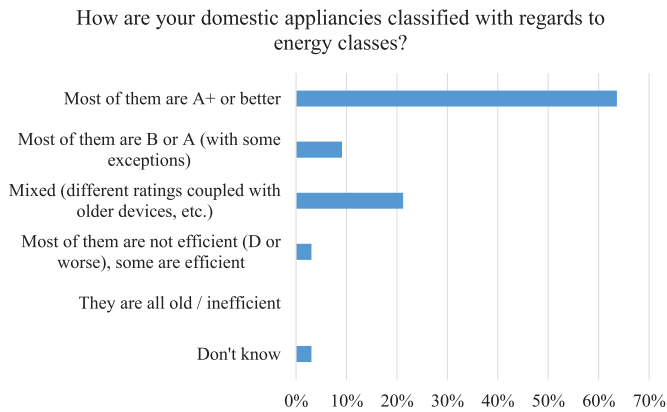


Fig. A13. Results of the questionnaire 2018.

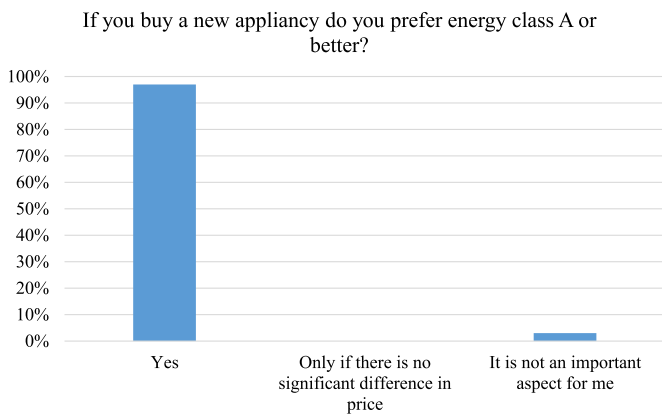


Fig. A14. Results of the questionnaire 2018.

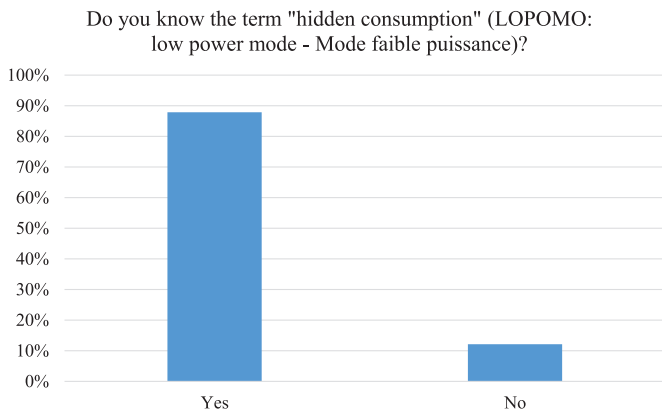


Fig. A15. Results of the questionnaire, 2018.

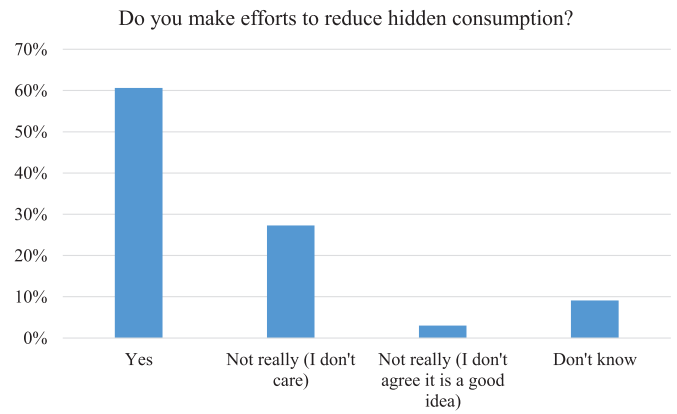


Fig. A16. Results of the questionnaire, 2018.

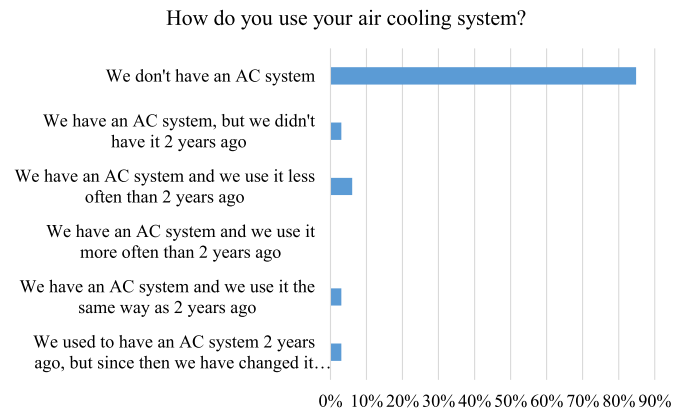


Fig. A17. Results of the questionnaire, 2018.

References

- [1] N. Kampelis, K. Gobakis, V. Vagias, D. Kolokotsa, L. Standardi, D. Isidori, et al., Evaluation of the performance gap in industrial, residential & tertiary near-zero energy buildings, *Energy Build.* 148 (2017) 58–73, doi:10.1016/j.enbuild.2017.03.057.
- [2] E. Delzendeh, S. Wu, A. Lee, Y. Zhou, The impact of occupants' behaviours on building energy analysis: a research review, *Renew. Sustain. Energy Rev.* 80 (2017) 1061–1071, doi:10.1016/j.rser.2017.05.264.
- [3] Z. Yu, B.C.M. Fung, F. Haghighat, H. Yoshino, E. Morofsky, A systematic procedure to study the influence of occupant behavior on building energy consumption, *Energy Build.* 43 (2011) 1409–1417, doi:10.1016/j.enbuild.2011.02.002.
- [4] D. Zhao, A.P. McCoy, J. Du, P. Agee, Y. Lu, Interaction effects of building technology and resident behavior on energy consumption in residential buildings, *Energy Build.* 134 (2017) 223–233, doi:10.1016/j.enbuild.2016.10.049.
- [5] J. Ouyang, K. Hokao, Energy-saving potential by improving occupants' behavior in urban residential sector in Hangzhou City, China, *Energy Build.* 41 (2009) 711–720, doi:10.1016/j.enbuild.2009.02.003.
- [6] C. Vogiatzi, G. Gemenetzi, L. Massou, S. Pouloupoulos, S. Papaefthimiou, E. Zervas, Energy use and saving in residential sector and occupant behaviour: a case study in Athens, *Energy Build.* (2018), doi:10.1016/j.enbuild.2018.09.039.
- [7] K.-U. Ahn, C.-S. Park, Correlation between occupants and energy consumption, *Energy Build.* 116 (2016) 420–433, doi:10.1016/j.enbuild.2016.01.010.
- [8] Y. Zhang, X. Bai, F.P. Mills, J.C.V. Pezzey, Rethinking the role of occupant behavior in building energy performance: a review, *Energy Build.* 172 (2018) 279–294, doi:10.1016/j.enbuild.2018.05.017.
- [9] B.F. Balvedi, E. Ghisi, R. Lamberts, A review of occupant behaviour in residential buildings, *Energy Build.* 174 (2018) 495–505, doi:10.1016/j.enbuild.2018.06.049.
- [10] C. Chang, N. Zhu, K. Yang, F. Yang, Data and analytics for heating energy consumption of residential buildings: the case of a severe cold climate region of China, *Energy Build.* 172 (2018) 104–115, doi:10.1016/j.enbuild.2018.04.037.

- [11] L. Wen, K. Zhou, S. Yang, L. Li, Compression of smart meter big data: a survey, *Renew. Sustain. Energy Rev.* 91 (2018) 59–69, doi:10.1016/j.rser.2018.03.088.
- [12] A. Al-Wakeel, J. Wu, K-means based cluster analysis of residential smart meter measurements, *Energy Procedia* 88 (2016) 754–760, doi:10.1016/j.egypro.2016.06.066.
- [13] B. Yildiz, J.I. Bilbao, J. Dore, A.B. Sproul, Recent advances in the analysis of residential electricity consumption and applications of smart meter data, *Appl. Energy* 208 (2017) 402–427, doi:10.1016/j.apenergy.2017.10.014.
- [14] K. Zhou, C. Yang, J. Shen, Discovering residential electricity consumption patterns through smart-meter data mining: a case study from China, *Util. Policy* 44 (2017) 73–84, doi:10.1016/j.jup.2017.01.004.
- [15] J.P. Gouveia, J. Seixas, A. Mestre, Daily electricity consumption profiles from smart meters - proxies of behavior for space heating and cooling, *Energy* 141 (2017) 108–122, doi:10.1016/j.energy.2017.09.049.
- [16] J.P. Gouveia, J. Seixas, Unraveling electricity consumption profiles in households through clusters: combining smart meters and door-to-door surveys, *Energy Build.* 116 (2016) 666–676, doi:10.1016/j.enbuild.2016.01.043.
- [17] X. Serrano-Guerrero, G. Escrivá-Escrivá, C. Roldán-Blay, Statistical methodology to assess changes in the electrical consumption profile of buildings, *Energy Build.* 164 (2018) 99–108, doi:10.1016/j.enbuild.2017.12.059.
- [18] Renz, I. The ICT PSP methodology for energy saving measurement - a common deliverable from projects of ICT for sustainable growth in the residential sector, 2012.
- [19] G. Woodall, SMART 2011 / 0072: methodology for energy efficiency measurements applicable to ICT in buildings (eeMeasure), D1.2 Non-residential Methodology, 2011.
- [20] International performance measurement and verification protocol, Concepts and Options for Determining Energy and Water Savings, 1, Efficiency Valuation Organization, 2012.
- [21] N. Mogles, I. Walker, A.P. Ramallo-González, J. Lee, S. Natarajan, J. Padgett, et al., How smart do smart meters need to be? *Build. Environ.* 125 (2017) 439–450, doi:10.1016/j.buildenv.2017.09.008.
- [22] C. Wang, D. Yan, H. Sun, Y. Jiang, A generalized probabilistic formula relating occupant behavior to environmental conditions, *Build. Environ.* 95 (2016) 53–62, doi:10.1016/j.buildenv.2015.09.004.
- [23] I. Richardson, M. Thomson, D. Infield, A high-resolution domestic building occupancy model for energy demand simulations, *Energy Build.* 40 (2008) 1560–1566, doi:10.1016/j.enbuild.2008.02.006.
- [24] H. Jang, J. Kang, A stochastic model of integrating occupant behaviour into energy simulation with respect to actual energy consumption in high-rise apartment buildings, *Energy Build.* 121 (2016) 205–216, doi:10.1016/j.enbuild.2016.03.037.
- [25] G. Happle, J.A. Fonseca, A. Schlueter, A review on occupant behavior in urban building energy models, *Energy Build.* 174 (2018) 276–292, doi:10.1016/j.enbuild.2018.06.030.
- [26] L. Diao, Y. Sun, Z. Chen, J. Chen, Modeling energy consumption in residential buildings: a bottom-up analysis based on occupant behavior pattern clustering and stochastic simulation, *Energy Build.* 147 (2017) 47–66, doi:10.1016/j.enbuild.2017.04.072.
- [27] Michael, D., Chen, S. *Serious games: games that educate, train and inform*. Boston: Thomson Course Technology; 2006.
- [28] J. Alvarez, D. Djaouti, An introduction to serious game - definitions and concepts, in: P. Fauquet-Alekhnine, L. Soler (Eds.), *Proceedings of the Serious Games & Simulation for Risks Management Workshop*, Paris, 2011, pp. 10–15. LARSEN Science 2011 - Laboratoire de Recherche pour les Sciences de l'Énergie.
- [29] N. Alvarez, M. Real, I. Lizarralde, J. Legardeur, in: *Ekit'eko Kit'eko: A Serious Game to Support Sustainable Aptitudes During the Development of Eco-Innovations, Management of Technology - Step to SustProduction*, Bol, Island Brač, Croatia, 2014, pp. 175–182.
- [30] E. Nieuwdorp, The pervasive discourse: an analysis, *Comput. Entertain.* 5 (2007) 1–17, doi:10.1145/1279540.1279553.
- [31] A.-G. Paetz, E. Dütschke, W. Fichtner, Smart homes as a means to sustainable energy consumption: a study of consumer perceptions, *J. Consum. Policy* 35 (2012) 23–41, doi:10.1007/s10603-011-9177-2.
- [32] A. Chamberlain, S. Benford, C. Greenhalgh, A. Hampshire, N. Tandavanitj, M. Adams, et al., Professor tando: greener gaming & pervasive play, in: *Proceedings of the 2007 Conference on Designing for User Experiences - DUX '07*, 44, 2007, pp. 1–17, doi:10.1145/1389908.1389942.
- [33] D. Johnson, E. Horton, R. Mulcahy, M. Foth, Gamification and serious games within the domain of domestic energy consumption: a systematic review, *Renew. Sustain. Energy Rev.* 73 (2017) 249–264, doi:10.1016/j.rser.2017.01.134.
- [34] W. Abrahamse, L. Steg, C. Vlek, T. Rothengatter, A review of intervention studies aimed at household energy conservation, *J. Environ. Psychol.* 25 (2005) 273–291, doi:10.1016/j.jenvp.2005.08.002.
- [35] A.R. Carrico, M. Riemer, Motivating energy conservation in the workplace: an evaluation of the use of group-level feedback and peer education, *J. Environ. Psychol.* 31 (2011) 1–13, doi:10.1016/j.jenvp.2010.11.004.
- [36] S. Darby, The Effectiveness of Feedback on Energy Consumption: Review for Defra of the Literature on Metering, Billing and Direct Displays, 22, Oxford, 2006, UK, doi:10.4236/ojee.2013.21002.
- [37] D. Vine, L. Buys, P. Morris, The effectiveness of energy feedback for conservation and peak demand: a literature review, *Open J. Energy Effic.* 02 (2013) 7–15, doi:10.4236/ojee.2013.21002.
- [38] R. Castri, D. Wemyss, F. Cellina, V. De Luca, V. Frick, E. Lobsiger-Kägi, et al., Triggering electricity-saving through smart meters: play, learn and interact using gamification and social comparison, in: *TEDDINET Energy Feedback Symposium 2016*, 2016, pp. 248–256.
- [39] V. De Luca, R. Castri, The social power game: a smart application for sharing energy-saving behaviours in the city, in: *Proceedings of the AVI 2014 Workshop on Fostering Smart Energy Applications through Advanced Visual Interfaces*, Como, Italy, 2014, pp. 1–4, doi:10.1145/2598153.2602224.
- [40] B. Gnauk, L. Dannecker, M. Hahmann, Leveraging gamification in demand dispatch systems, in: *Proceedings of the 2012 Joint EDBT/ICDT Workshops on - EDBT-ICDT '12*, Berlin, Germany, ACM, 2012, pp. 103–110, doi:10.1145/2320765.2320799.
- [41] M. Shiraiishi, Y. Washio, C. Takayama, V. Lehdonvirta, H. Kimura, T. Nakajima, Using individual, social and economic persuasion techniques to reduce CO2 emissions in a family setting, in: *Proceedings of the 4th International Conference on Persuasive Technology*, Claremont, California, USA, ACM, 2009, pp. 1–8, doi:10.1145/1541948.1541967.
- [42] A. Gustafsson, C. Katzeff, M. Bang, Evaluation of a pervasive game for domestic energy engagement among teenagers, *Comput. Entertain.* 7 (2009) 1–19, doi:10.1145/1658866.1658873.
- [43] A. Gustafsson, M. Bång, M. Svahn, Power explorer: a casual game style for encouraging long term behavior change among teenagers, in: *ACE '09 Proceedings of the International Conference on Advances in Computer Entertainment Technology*, Athens, Greece, ACM, 2009, pp. 182–189, doi:10.1145/1690388.1690419.
- [44] C.A. Björkskog, G. Jacucci, L. Gamberini, T. Nieminen, T. Mikkola, C. Torstensson, et al., EnergyLife: pervasive energy awareness for households, in: *Proceedings of the 12th ACM International Conference Adjunct Papers on Ubiquitous Computing-Adjunct*, Copenhagen, Denmark, ACM, 2010, pp. 361–362, doi:10.1145/1864431.1864436.
- [45] P. Centieiro, *Mobile Persuasive Interfaces for Public Ambient Displays*, Universidade Nova de Lisboa, 2011.
- [46] R.N. Madeira, A. Vieira, N. Correia, Personalization of an energy awareness pervasive game, in: *Proceedings of the 2012 ACM Conference on Ubiquitous Computing - UbiComp '12*, Pittsburgh, Pennsylvania, USA, ACM, 2012, pp. 619–620, doi:10.1145/2370216.2370333.
- [47] D. Geelen, D. Keyson, S. Boess, H. Brezet, Exploring the use of a game to stimulate energy saving in households, *J. Des. Res.* 10 (2012) 102–120, doi:10.1504/JDR.2012.046096.
- [48] J. Simon, M. Jahn, A. Al-Akkad, Saving energy at work: the design of a pervasive game for office spaces, in: *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia - MUM '12*, Ulm, Germany, ACM, 2012, pp. 1–4, doi:10.1145/2406367.2406379.
- [49] L. Gamberini, A. Spagnoli, N. Corradi, G. Jacucci, G. Tusa, T. Mikkola, et al., Tailoring Feedback to Users' Actions in a Persuasive Game for Household Electricity Conservation, in: M. Bang, E.L. Ragnemalm (Eds.), *Proceedings of International Conference on Persuasive Technology*, Springer, 2012, pp. 100–111, doi:10.1007/978-3-642-31037-9_9.
- [50] R.N. Madeira, A. Silva, C. Santos, B. Teixeira, T. Romão, E. Dias, et al., LEY! pervasive pervasive gaming on domestic energy, in: *Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology*, Lisbon, Portugal, ACM, 2011, pp. 1–2, doi:10.1145/2071423.2071512.
- [51] L. Wells, K.De. Salas, I. Lewis, A. Berry, Behaviour change wheel driven normative feedback in a serious game for energy conservation, in: *Proceedings of 1st International Joint Conference of DiGRA and FDG*, 2016, pp. 1–16.
- [52] M. Casals, M. Gangolells, M. Macarulla, A. Fuertes, R. Jones, S. Pahl, et al., Promoting energy users' behavioural change in social housing through a serious game, in: *Proceedings of ECPPM 2016: 11th European Conference on Product and Process*, Limassol, Cyprus, 2016, pp. 1–6.
- [53] Oigimet weather information service 2018. <http://ogimet.com/index.phtml.en>.