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# Empowering and Engaging European building users for energy efficiency

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ABSTRACT

Amidst the challenge of improving energy efficiency in the built environment, increasing attention is being put on how to engage and empower building users. Research shows that improving and widening user engagement, such as involving users in co-designing interventions, has potential to foster greater acceptance and impact. In this context, Information and Communication Technology (ICT) has a major role to play, through feedback tools, smartphone or web-based apps, interactive dashboards and gamification. However, there are few empirical accounts exploring how user engagement can effectively shape development of an ICT-based energy efficiency intervention.

This paper presents findings from the eTEACHER project which aims to empower building energy end-users to reduce energy consumption through a set of related ICT-based interventions. These interventions, including a web-based app and building-specific 'what-if' analysis have been developed by drawing upon feedback from pilot users in 12 buildings, including both residential and non-domestic, across three EU countries. A structured evidence-based approach to user engagement was followed, which included site visits, a series of building user workshops and a questionnaire.

The paper reflects on the challenges and benefits of empowering and engaging building users across a wide range of building types, residential, offices, schools and health care centres using a single app. Our findings show common challenges across building types in tackling existing inefficient energy behaviours. However significant hurdles were encountered in implementing the ICT-based interventions, which are building specific. Based upon this, recommendations on how engagement processes can support the development of ICT-based interventions are put forward.

## 1. Introduction

To pursue the goal of energy efficiency in buildings through changes in user behaviour, Information and Communication Technologies (ICT) are increasingly being used to provide information or 'feedback' to overcome what is known as energy invisibility [1]. This is being done through display monitors, interactive dashboards, building energy management systems (BEMS), and a range of web-based apps that attempt to make energy use visible to building users [2–4]. Such measures have achieved a varying degree of success in terms of actual energy savings. In their substantial early work over 20 years ago Burgess and Nye noted [1] potential savings of between 5 and 15%. More recent research has shown savings to be possible between 10 and 20% e.g. [5,6], though all agree that there is no simple causal relationship between installing ICT-enabled feedback and subsequent behaviour change.

More recently, researchers have called for interventions to move beyond feedback and instead to design behaviour change initiatives around the wider social, organisational and cultural context of energy use, whether at home or in a workplace [7,8]. Initiatives that move beyond 'mere feedback' have examined linkages between ICT-based interventions and a wider community setting through, for example, the use of social media [9–12]. Involving users in the co-design of behaviour change interventions is an increasingly used approach to enhance their acceptance and resulting impacts. To follow this approach to promote energy conservation in buildings implies that organisations would need to adopt a more participatory approach to energy management [13,14]. In a comprehensive review of over twenty energy-saving behaviour change interventions in the workplace Staddon et al. [15] note that the most successful initiatives had a combination of technological automation *and* 'enablement' – that is, opportunities for building users to move beyond education and training.

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This paper responds to this context by discussing a recent European Union (EU) Horizon 2020 (H2020) project, eTEACHER, that began in October 2017 and has employed principles of user-involvement and empowerment to enhance the design of an ICT-based tool to promote energy conservation in buildings. The eTEACHER tool is being developed and piloted over three years, working with twelve domestic and non-domestic case study buildings, including residential apartments, schools, health care centres and offices, in Spain, the UK and Romania. The paper seeks to add to an increasing evidence base around both the benefits and challenges of user engagement based upon empirical data from a range of approaches that eTEACHER has utilised: building user workshops, questionnaires and site visits. Whilst user engagement for energy efficiency initiatives has been advocated for some time (e.g. [16]), empirical accounts of learning from the process are still scarce [17].

This paper not only focuses on developing further knowledge of user engagement in energy conservation interventions but also reports on the incorporation of user engagement with the development of ICT-based behaviour change tools. In so doing, the paper seeks to identify the challenges faced with developing an empowering ICT-based tool through user engagement and analysis of the motivation and agency of a range of building users across different building types and across different European locations.

## 2. Background

Energy use in buildings is resultant of wide-ranging individual and contextual factors. Whilst much is known about the influence of contextual factors such as the efficiency of energy systems and influence of building controls, quantifying the impact of occupant behaviour is often difficult [18,19]. Individual and social factors can be a significant influence, such as norms of behaviour, the ability and agency for using energy systems in buildings, and users' understanding of how energy systems work. Wei et al. [20] highlighted that occupants' space heating behaviour alone can be influenced by 27 different factors. ICT is not new but developments in its use relating to energy saving in buildings have become far more prominent over the last decade. The extent to which ICT has been used in domestic and non-domestic buildings in recent years has varied with many studies focusing on the impact of in-home-displays in the domestic sector, whilst more-novel methods, such as gamification, have often been tested in the non-domestic sector. The use of ICT offers a wealth of opportunity to both manage energy efficiency in buildings, and to intervene and/or engage with building users to promote more energy efficient behaviours.

A well-researched energy behaviour change intervention that can shed light upon ICT-based approaches in the domestic setting is the implementation of In-Home Displays (IHDs) to provide near real-time feedback on energy consumption. They can achieve electricity consumption savings if users engage with the feedback, however a broad range of responses to feedback have been found [21]. Hargreaves et al. [22] highlight differing degrees of user engagement with domestic displays and suggests this is due to the varying constraints of social relationships and practices in different households. Buchanan et al. [23] argue that providing feedback alone is insufficient to achieve significant carbon emission reductions from housing, given that short-term reductions are only 2% on average. Although IHDs can improve knowledge and confidence about energy consumption, they do not always motivate residents to decrease their energy use over the long term as they can blend into the background [24]. In terms of how IHDs are implemented and linkages to impacts, several studies have found greater acceptance when they fit into householders' routines and home aesthetic [25,26]. Weiss et al. [27] suggest the use of smartphones over IHDs to increase active engagement, emphasising that most individuals already own and use smartphones, and indeed, a range of app-based home energy management systems have emerged in recent years. Thus, IHDs demonstrate potential for ICT-based interventions to achieve some energy consumption savings, but face challenges around securing ongoing engagement of householders and adapting to a context of wider technological changes affecting householder behaviour.

Non-domestic buildings are also an important research priority as they give rise to approximately 18% of the UK's carbon emissions [7]. An example of inefficiency in this sector comes from energy used for computing in offices, which makes up approximately 30% of energy demand in the European service sector [28]. Mulville et al. [29] highlighted that much of this equipment is under-utilised and frequently left on overnight, giving significant opportunities for efficiency savings. More widely, workplaces offer new opportunities for ICT-based energy feedback, such as through the use of display screens in communal areas [30,31], though their impacts on energy saving remain unclear [15]. Behaviour change interventions within workplaces face additional challenges such as limits to the agency of building users (e.g. ability to control heating) and organisational policies and processes (e.g. affecting use of IT systems) [32] which can impact the motivation and engagement of non-domestic building users towards energy conservation.

Sustaining engagement with ICT-based interventions such as IHDs and web-based apps can prove challenging, and gamification has emerged as one potential solution. Gamification refers here both to creating 'serious games' that aim to be both entertaining and educational [33] and using the motivational principles behind game design to improve the engagement and enjoyment of users in other types of interaction [34,35]. This could be as simple as a points-based competition between buildings or neighbourhoods, or as sophisticated as a web-based app with energy avatars. In a systematic review of gamification's use for energy conservation projects, Johnson et al. [36] highlight significant potential benefits (e.g. in motivation and learning), but a shortage of robust empirical evidence of its impacts. Some of the positive impacts from empirical studies of energy-focused gamification apps include increased energy awareness [37], more-positive attitudes towards energy saving [38] and improved energy-related knowledge [39]. Grossberg et al. [35] advise that effective game designs are carefully tailored to the specific user audience and integrate social media (e.g. Facebook, Instagram) to reward efforts and amplify impacts. Wood et al. [40] also highlight the importance of peers being able to compare performance socially, setting clear and achievable goals and linking actions to real-world energy use to enhance energy literacy. Similarly, Senbel et al. [41] found that their intervention's success in reducing energy consumption stemmed not from the competitive point scoring against unknown peers, but in the communication of stories and experiences with personal friends. These studies therefore highlight that the core principles of gamification, including motivation through competitions and peer to peer comparison in social networks, hold good potential to form part of interventions to reduce energy consumption in an engaging manner.

Specific behaviours and behaviour change interventions can always be understood as taking place within a 'wider system' [42], and this insight has particular relevance in the non-domestic sector. The concept of 'building communities' [13] recognises that energy-related behaviours in buildings are embedded in specific social and technological contexts, which warrant consideration beyond a focus on 'individual' behaviour. Forming a community or creating a platform for expression of existing community links allows users to feel part of a collective effort that can amplify their impact. Examples of this principle in practice include using physical user meetings to complement ICT-based engagement and allowing building users to flag issues and request solutions in an online forum [7,12]. Given the increased desire to amplify social interaction within behaviour change interventions, it follows that social media could also prove an invaluable mechanism for interventions. This could be done through entirely new bespoke ICT-based platforms, or by "piggybacking" on existing popular sites, utilising pre-existing habits of frequent engagement rather than attempting to solicit regular use of a new login and unfamiliar system [43]. For example, social media has been used to launch and energise an energy-saving competition between 6500 students at a University campus [41] generating increased motivation through the actions and stories of friends, rather than scores of unknown peers. However, social media use also poses specific challenges, particularly within organisational settings where issues of privacy and trust can compromise an employee's willingness to take part [44].

Increasingly, researchers and practitioners are recognising that active user engagement is not only a key factor for successful implementation of behaviour change interventions, but that intervention design can be enhanced by target users' active participation throughout the design process [45-48]. For ICT-based interventions, this suggests a user-centred design approach [16] of iterative refinements with user input, so that the final output will accommodate users' needs and wants, thereby increasing the chance of intensive and prolonged engagement [49]. For energy use in buildings, active user engagement during development stages can draw out the diversity of needs of different groups of building users, reducing the risk of one-size-fits-all strategies being developed which fail to meet all users' needs [50]. Thus, user engagement approaches are particularly beneficial for targeted and tailored interventions that treat each group of users according to their characteristics [51]. User engagement approaches to energy saving projects therefore place emphasis on the importance of in-depth user studies [52] and aim to enhance impacts through personalised and context-aware interventions [44,53–55].

Thus, ICT-based behaviour change interventions for energy efficiency in buildings hold promise, but as shown in this section, they face specific challenges around motivating sustained engagement and participation from target building users. This paper explores what can be learned about the role of user engagement in ICT-based behaviour change from the development of the eTEACHER project. This project aims to successfully employ principles of empowerment and engagement across a variety of building users, across domestic and non-domestic buildings. It highlights the opportunities and challenges associated with developing an ICT-based tool which can be implemented in a range of building types. Through engaging all building user groups throughout development, the tool offers an opportunity to explore the merits of a one-size-fits-all solution to empower a multitude of end users in energy efficient behaviours.

## 3. Methodology

### 3.1. Case study Project: eTEACHER

The eTEACHER project, end-users Tools to Empower and raise Awareness of behavioural CHange towards EneRgy efficiency, is a three-year project being delivered by a consortium of twelve partners across six different countries. eTEACHER aims to empower energy end-users to achieve energy savings and improve health conditions and comfort in various building typologies. The project aims to enable behaviour change through a set of linked ICT-based solutions. These include enhancements to Building Energy Management Systems (BEMS) and user-friendly web-based apps and online dashboards. Unlike many previous behaviour change projects, eTEACHER is being piloted in twelve pilot buildings (Table 1), purposely chosen to allow for variations in location, typology and building users. This allows for the different challenges and opportunities to be identified across a range of building and user types and identify the factors influencing energy consumption behaviours which need to be considered for any ICT-based solution to be effective, particularly an ICT-based solution which can meet the needs of users across the range of building types.

The project aims to enhance knowledge and practice in two areas: firstly, by developing an ICT-based intervention that can support energy efficient behaviour change in a wide range of contexts; and secondly by exploring how engagement with pilot users to develop the eTEACHER tool can shed light upon effective participatory design of behaviour change interventions for energy efficiency. The project incorporates user perspectives in a pragmatic manner to identify the opportunities and limitations of an ICT-based energy behaviour change intervention in multiple building types and across different European locations. It allows for common challenges and opportunities for energy related behaviour change to be identified through user engagement methods in order to develop an ICT-based intervention which empowers a range of building users, across different contexts, towards energy efficiency.

To embed a user-centred design approach within the project, the Enabling Change approach [45] was selected to structure user engagement with development of the eTEACHER tool. Enabling Change aims to synthesise evidence-based insights on behaviour change design, drawing on both theory and practice, to provide an accessible framework for the development of change initiatives. The approach includes two levels of planning: *programme level* and *project level*. Programme level planning defines the medium- and long-term objectives of the intervention and draws upon preliminary scoping of available research and knowledge by including the target audience in informal discussions and/or focus groups. Project level planning focuses on the practicalities of carrying out interventions, with an emphasis on ensuring the intervention is appropriate for the target audience. This level involves identifying target actors and their desired actions, investigating the needs and concerns of stakeholders, considering ways in which the action can be more beneficial and easier to carry out and drawing upon behaviour change interventions with a track record of effectiveness in the context under consideration. Robinson [45] recommends ongoing involvement and engagement of target users through the creation of a 'Brains Trust', an advisory group of target audience members and other supportive stakeholders. For the eTEACHER project, this principle has been applied by running initial building user workshops for each case study building and subsequently with continued engagement with the key actors through use of "Feedback Forums" during the development and implementation phases of the project.

### 3.2. Research methods

The study required a focus on multiple factors including the case study buildings, the building users, and the interactions between buildings and users to identify the opportunities and challenges affecting energy saving and the effective design and implementation of an ICT-based tool. A mixed method approach was therefore adopted, to accommodate the diversity of users and building typologies within the eTEACHER sample. Three complementary data collection methods were used in the project's first year to collect relevant information: pilot site visits; building user workshops; and a building user questionnaire. Given the variation in building types used as pilot buildings, the resulting data analysis has allowed for comparisons to be made across building types relating to the challenges and opportunities of implementing an effective ICT-based behaviour change intervention.

#### 3.2.1. Pilot site visits

Site visits were carried out in each pilot building by the lead author and project partners as the initial data collection method. These were undertaken to gather relevant data on each building, to better understand the building users and to identify the potential to implement behaviour change interventions. During the visits, a structured template was used to gather data on five key areas: 1: Categories of building users, including any influential "middle actors" [32] who sit midway in organisational hierarchies; 2; The primary function of the building; 3: The energy systems and Building Energy Management System (BEMS) installed; 4: Energy use data currently available for electricity and heating; and 5: Any distinctive energy-inefficiency behaviours currently taking place. The site visits involved collecting observational data as well as informal interviews with key building actors, typically including the building manager (BM) or facility manager (FM). These took place during guided tours of each building, allowing for additional information to be collected for each of the five key areas.

**Table 1**
Summary of eTEACHER pilot building characteristics.

| eTEACHER pilot building | Location | Building use | Building type | No. of building users |
|---|---|---|---|---|
| InCity (4 separate blocks) | Bucharest, Romania | Residential | Private | 1500 |
| Villafranca | Spain | Health Centre | Public | 915 |
| Guareña | Spain | Health Centre | Public | 577 |
| Torrente Ballester | Spain | High School | Public | 520 |
| Arco Iris | Spain | Kindergarten | Public | 120 |
| OAR Badajoz | Spain | Office | Public/Private | 130 staff + public visitors |
| Residential Block | Spain | Residential | Private | 95 |
| Council House | Nottingham, UK | Office | Public | 40 staff + public visitors |
| Djanogly | Nottingham, UK | High School | Public | 800 |

*3.2.2. Building user workshop and questionnaire*

An initial workshop was used at each pilot building as a means to build rapport with building users through activities based around ICT engagement. The workshop collected data on users' ICT usage practices (at work and in their personal life) and opinions on potential eTEACHER designs and functions. The workshops were delivered by pilot building partners in the local language, using a uniform template to generate consistently formatted results from the information generated during the sessions. Each session was designed for 8–12 participants, representing all user profiles deemed necessary – both those using the building every day and relevant facility management staff (see details in Table 2). Attendees were split into groups, each with their own facilitator to guide the completion of the workshop activities and steer discussions. Activities were designed to be colourful, hands-on and mentally stimulating, making the experience memorable and to form a positive association with the project, supporting continued engagement.

Data on the target actors and their energy-related behaviours was also collected from a user questionnaire. The questionnaire design was informed by initial findings from the site visits and therefore covered seven areas: user demographics; ownership and use of ICT devices; mode of use of the pilot building; energy-related behaviours, attitudes and awareness; thermal comfort satisfaction; users' motivation to engage with eTEACHER; and the impact of social norms on behaviour. These questions were shaped by the 'COM-B' model of behavioural influences [42], which highlight that capability, social and physical opportunity and motivations interact to influence behavioural outcomes. The questionnaire was utilised to gather more information relating to the demographics of building users, their current energy behaviours, motivations and their acceptance of ICT. Questionnaires were completed by 110 participants in building user workshops (2 participants from the Spanish residential block chose not to complete the questionnaire). In addition, four further staff (including FM, cleaner and security) at the Spanish OAR office building and one further staff member (FM) at the UK Council House completed the questionnaire, giving 115 responses in all. This represents 2.5% of the total number of users across all eTEACHER pilot buildings. Although this represents a low proportion of total users, responses were received from all target user groups identified during the site visits.

## 4. Results

### 4.1. Site visits

The site visits enabled all building users and influential middle actors to be identified, informing engagement for subsequent workshops/ questionnaires, and a range of building-specific issues affecting energy use and user engagement (Table 3). A thematic analysis of the documentation produced following the site visits, including observational data, uncovered two key user engagement challenges towards implementing energy conservation measures found across all pilot buildings.

Firstly, relatively low levels of agency to influence energy consumption within the buildings, as in each case, decisions about installed energy using infrastructure were taken externally, not by building users, including within the residential apartments. Furthermore, in some cases energy management policies reduced the agency of users. For example, in the Health Centres in Spain energy infrastructure purchase and maintenance are all managed externally by the Regional Public Health Service. Residential users are restricted as to the maximum internal temperature they can achieve, as the maximum set-point is set by the facility management. Similarly, site visits uncovered restrictions to user's agency through building infrastructure such as tamperproof boxes encasing thermostats, lighting controls being located in different rooms to those they control, tamperproof radiator valves and thermostats only being accessible to certain building users, predominantly facility managers.

Secondly, user awareness of energy consumption was found to be a key challenge. This is impacted by the great level of variation in how energy use is metered and monitored across the case study sites. For

**Table 2**
Summary of building user workshops.

| Location | Pilot building | Group size | Percentage of total building users | User roles present | Demographics |
|---|---|---|---|---|---|
| United Kingdom | Council House | 10 | 25% | Admin staff, cleaning staff, City Councillor | Age range: 11–60 + Language spoken: English |
| | Djanogly | 22 (over 2 workshops) | 3% | Teachers, other staff (including. admin, cleaning, chef), students | |
| Romania | InCity (4 buildings) | 39 (over 2 workshops) | 3% | Facility manager, technical crew members, owners and tenants, building visitor | Age range: 18–60 Language spoken: Romanian |
| Spain | Torrente Ballester & Arco Iris | 8 | 1% | Staff (including teachers, FM, admin) and students (high school only) | Age range: Majority 40–69 Language spoken: Spanish |
| | Residential block | 5 | 5% | Owners and building manager (also owner) | |
| | Villafranca | 9 | 1% | Staff, building manager, facility managers (external companies), cleaner | |
| | Guareña | 9 | 2% | Staff, building manager, cleaner | |
| | OAR Badajoz | 10 | 8% | General Staff | |

**Table 3**
Summary of learning from site visits.

| Building type | Pilot building | Monitoring data available | | | In-house Energy Management | Comfort Issues | Energy Inefficiencies | Engagement Issues |
|---|---|---|---|---|---|---|---|---|
| | | *Electricity* | *Heating* | *BEMS* | | | | |
| DOMESTIC | InCity, Romania | Yes | Yes - district heating and gas back-up boilers. | Yes | Yes | Thermal discomfort in extreme weather (very cold winters but very hot summers). | Efficiency of dealing with residents' complaints or building issues. | Getting residents on board to participate. |
| | Residential Block, Spain | Yes, whole building | Natural gas, (through 3rd party) | No, heating system centrally controlled | Yes | | Lights Heating unused areas.<br>Unused appliances left on. | Getting residents on board to participate. |
| HEALTH CARE | Villafranca, Spain | Yes - by: lighting; HVAC; chiller; ventilation; appliances. | Yes - electric | No, basic temp control set-point for heating and cooling | No, externally managed | Thermal discomfort. Some areas of building reported as being too hot, whereas others suffer from drafts. | HVAC on in unused areas.<br>Lights.<br>Windows open in heating season<br>Heating location<br>Thermostat locations | No in-house maintenance team – all external companies. |
| | Guareña, Spain | Yes, broken down by lighting, HVAC, appliances | Yes – electric heat pumps | No, basic temp control set-point for heating and cooling | No, externally managed | Thermal discomfort. Areas of building reported as being too hot or too cold due to incoming sun and drafts from entrances. | HVAC on in unused areas.<br>Lights.<br>Thermostat locations | No in-house maintenance team – all external companies. |
| SCHOOL | Torrente Ballester, Spain | Yes, whole building | Yes – oil boilers, metered | No | No | Thermal discomfort from some classroom deemed too hot or too cold with lack of individual room control. | Lights.<br>Computers and projectors.<br>Windows open in heating season | Students not allowed to use smart phones. |
| | Arco Iris, Spain | Yes, whole building | Oil boiler, metered | No | No | . | Lights.<br>Heating unused spaces.<br>Inefficient appliances | Staff the only target group - other users aged 3 years and under. |
| | Djanogly, UK | Yes | Yes, Natural gas | Yes | No, energy facility staff | Thermal discomfort.<br>Classrooms often too hot or too cold with lack of individual control. Issues from incoming sun.<br>Main hall often very cold | Lights<br>Computers and projectors | Facility crew checks lights/ appliances are off at end of day.<br>Students not allowed to use smartphones.<br>Staff workloads will limit potential engagement.<br>Tamper-proof radiator valves |
| OFFICE | OAR Badajoz, Spain | Yes, lighting, HVAC, appliances. | Yes – electric | Yes, not utilised as BEMS however | No | Thermal discomfort. Temperature variation across office floor. Some areas very hot, others too cold. | Use of personal heaters.<br>BEMS control – Cleaners switch lights and HVAC system on/off daily | Keen environmental motivation<br>Staff cannot alter thermostats |
| | Council House, UK | Yes | Yes, district heating (also includes adjacent unused building) | No, central control of HVAC only | No, energy facility staff | Thermal discomfort with vast variations in temperature across building. Issue from drafts in main entrance.<br>Lighting levels. | Lights<br>Use of personal heaters. | Caretaker keen on energy efficiency but cannot see any energy data.<br>Listed building - building fabric needs upgrade<br>Lighting controls often not in relevant locations.<br>Tamper-proof radiator valves |

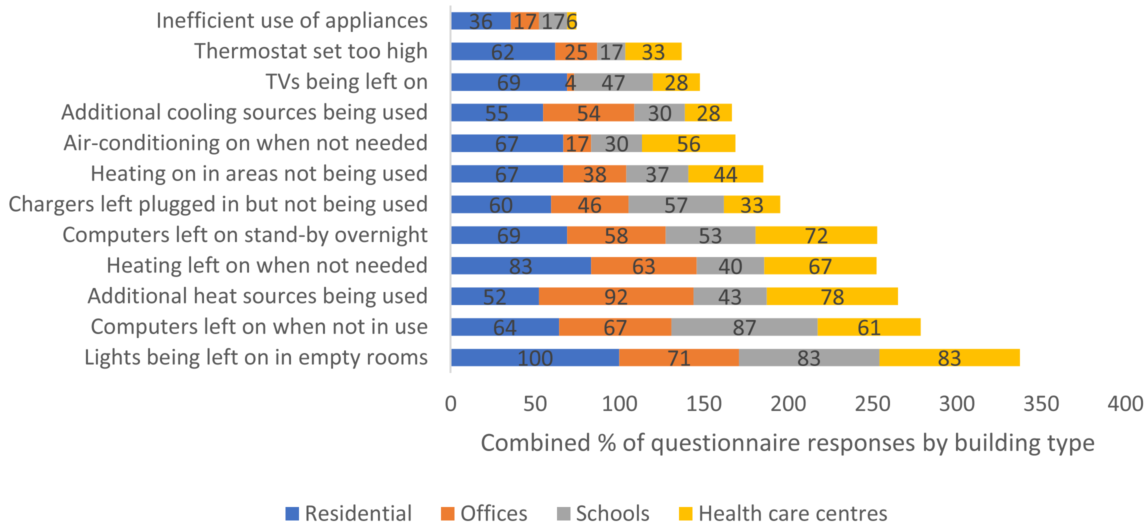


**Fig. 1.** Current reported inefficient energy behaviours by building user questionnaire responses.

electricity, while some buildings have electricity use broken down by function, others only have bill data at a whole building level. Similarly, for space heating, data is typically available only at a whole-building level, but with differing units and frequencies of measurement (gas used; electricity used; oil consumed). Even when energy use is metered in buildings, some users stated that they are only aware of the energy consumption through bills (quarterly or in the case of Arco Iris, biannually). In the residential properties, users' bills do not only include their own consumption but also charges towards shared communal space consumption and maintenance costs. User access to monitored energy consumption was limited in many of the buildings with more advanced monitoring, with this data only accessible to external stakeholders (building managers) and not by building users themselves. This situation highlights the difficulty of developing a "one size fits all" tool that can accept meaningful data from a wide range of building types given the differing current levels of monitoring and the need for more consistent data collection. For the purposes of this project, eTEACHER is adding smart meters in buildings where monitoring data is not available to ensure that the tool can receive relevant energy consumption data, but this highlights a challenge around relying on existing energy monitoring installations if an app such as eTEACHER was rolled out more widely. This issue is made more challenging in buildings such as the Heritage England Grade II listed Council House, where legal restrictions as a result of its architectural heritage affect the monitoring equipment that can be installed. Similarly, the project is restricted in that it is not possible to make improvements to building energy systems. Instead, energy savings are reliant on increasing the awareness and engagement of building users to demonstrate more energy efficient behaviours based on tailored recommendations generated from monitored energy consumption.

The analysis of observational data collected during the site visits found similarities in terms of the behaviour and comfort issues identified and highlighted common inefficiencies where equipment (lighting/heating/cooling/PCs) were being left on when not needed. Thermal comfort was a commonly raised theme, though issues raised were highly specific (e.g. users feeling cold in particular rooms) and would require changes to specific room settings rather than whole building settings. In several cases there was evidence of increased energy consumption due to thermal discomfort, such as windows being left open when heating was turned on, or individual electric heaters being used to complement central heating. However, it was noted that only a small number of users actually had the capacity to change building control settings, particularly with HVAC systems, and therefore the majority of building users were again restricted in what they could do.

Finally, in terms of engagement with energy and with eTEACHER, the site visits highlighted motivational influences on engagement (e.g. interest from some in energy efficiency, or disinterest from others). In fact, some of the pilot buildings (the Spanish office building and both High Schools) had evidence of previous energy efficiency campaigns (e.g. posters dedicated to behavioural actions to reduce consumption). However the analysis found some disinterest in the project due to a lack of communication between building users, particularly between those who agreed to be part of the project and the key building stakeholders relevant to the project. Similarly, access to ICT was identified as a possible constraint to engagement with an eTEACHER app, such as users not being permitted to use smartphones on site or being restricted in usage of smartphones and/or websites by organisational policy. Given that user engagement is vital to the success of such interventions such as the eTEACHER tool, it was important to assess the level of motivation for such measures via the questionnaire.

### *4.2. Building user questionnaire*

The questionnaire (see Appendix A) sought to identify the most common energy-related behaviours where respondents saw potential to make energy savings. Across the 115 questionnaires, all of the different target user groups were represented (detailed in Table 2) covering between 1 and 28% of the total building users.

Within the questionnaire, participants were asked to indicate which inefficient energy behaviours they were aware of taking place in their own building, as shown in Fig. 1. Across all buildings the most prominent issues related to lighting, heating and appliances being left on when not needed. This highlights that even across different building types there are similar opportunities to improve energy efficiency.

In terms of comfort-related behaviour, such as heating use, the opportunity for users will depend on their agency to control heating and cooling to achieve thermal comfort. A high proportion of users reported adjusting their thermal environment by opening and closing of windows or through the use of window blinds or shades. Adjusting thermostat settings or radiator valves was found to be most prominent in residential buildings and the Health care centres, however users of these buildings have easy access to these controls, unlike the users of the office or school buildings. Across all responses 11% of residential users and 27% of non-residential users indicated that they had no control over the thermal environment of the building. Those with little or no control often need to contact the energy manager or facility management teams to request that something is done to improve their comfort. However, only 21% of residential building users and 30% of

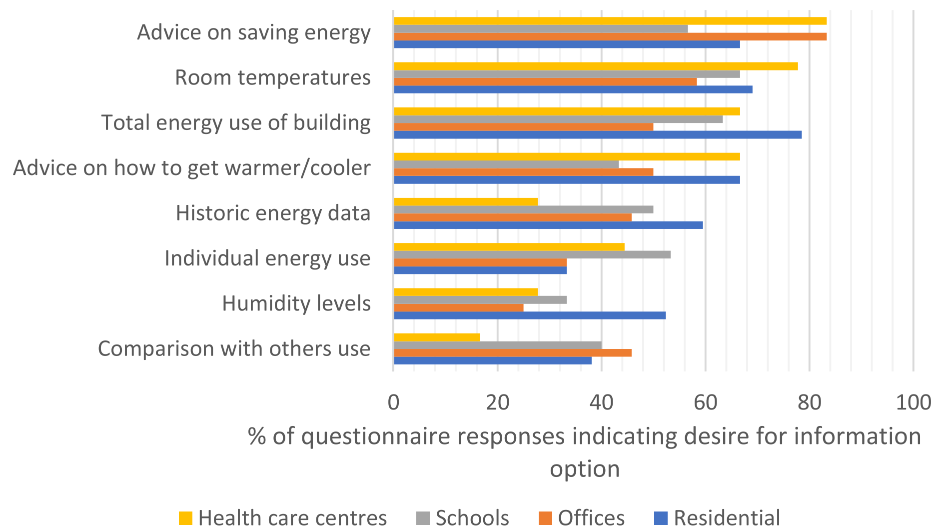


**Fig. 2.** Preference for specific energy-related information by building type.

non-residential users said that they had reported an issue within their building relating to energy use and/or their own comfort. The main reasons behind this lack of reporting was identified as; users not having enough time (11%) and users not knowing the relevant person to contact (7%).

Saving energy was reported as being important across all pilot buildings (82% said this was very important). Thus, the people that responded to the survey were a relatively supportive group. This support was reflected in 90% of users expressing interest in knowing more about the energy used their building. The most strongly supported approaches for learning more were through data on total energy consumption and individual room temperatures, and receiving energy saving advice, as shown in Fig. 2.

Users were asked how they could benefit from using an ICT-based tool, such as a mobile phone application or an interactive dashboard. The most important factors for users were environmental impact, cost and personal comfort. Cost was of relatively high importance for residential users with 54% selecting it as the most important factor for them. This suggests that energy-related information should be linked to other factors such as cost or environmental impact to make the information more relatable.

With any energy behaviour intervention, user engagement is a crucial part in the success of interventions, particularly those which rely on interaction from users, such as apps or dashboards. Therefore, understanding the most effective engagement methods within eTEACHER was vital. Most users (77%) reported being likely or very likely to engage actively with an ICT-based tool such as a mobile phone app. Users were asked what would motivate their participation, as shown from overall most motivating at the top to least in Fig. 3. Personalised energy use information was seen to be one of the main incentives for engagement across all building types, alongside significant environmental impact. Within the residential buildings users reported to be motivated the most by monetary rewards (62%), indicating that engagement within the residential sector requires a significant benefit to them personally.

All respondents were interested in hearing ideas from others such as energy saving tips and building improvement suggestions. This was the same kind of information that users were most happy to share with others from their own experiences. This suggests that there is the potential to develop "building communities" to further enhance engagement around the sharing of energy-related tips, hints and tricks. In terms of how to promote eTEACHER, respondents most strongly supported posters around buildings, emails and announcements on TVs/screens.

### 4.3. Building user feedback workshops

The user workshops identified several principles for design of the eTEACHER app. Common themes across all building types included the desire for simplicity and convenience in relation to the ICT-based tool. Simplicity was defined across all buildings as being something which was not overly technical. However, those in the non-domestic buildings also referred to simplicity in terms of not requiring excessive scrolling and requested flexibility by allowing for information to be displayed in different "layers". Across all building types, convenience was deemed to be a tool which allowed users to also have control over different settings. Building users stated that the tool should not be too onerous to use or to understand. Several users also expressed an interest in seeing real-time consumption, in an easy to understand format. Being able to see changes and gain a sense of achievement from making a difference was reported as supporting motivation.

Several potential barriers to take-up were also identified. A key barrier identified was limited time to use the app and what to do about non-participation from others in the building. This was particularly prevalent in the non-residential buildings, for which their core function (e.g. schools, offices and health care centres) was viewed as a priority rather than additional actions which could be deemed as another "task". In terms of gamification, most users did not wish to engage with eTEACHER as 'a game' to be played, as this was perceived as wasting time when they had higher priorities. However, users were open to the app having game-like elements to motivate use. There was caution about game-like elements such as competitions which could be potentially unfair given the different time and energy demands of different job roles. Most users were not interested in feedback on the carbon footprint of their behaviour, but data on energy use and money savings were often of interest.

A key insight identified regarding the opportunity to use eTEACHER was that school students are not permitted to use smartphones, therefore prohibiting their use of an app-based tool. Similarly, energy facility staff members in one building did not have access to a smartphone. This points to designing a multiplatform functionality allowing additional ICT devices (such as tablets, PCs and screens in communal spaces) to be used for eTEACHER or similar ICT-based interventions.

Users were given the opportunity to specify their "ideal" ICT-based tool, from its functionalities to what it should look like, and asked to identify what might motivate them or restrict them from using the tool. This activity highlighted the differences between pilot buildings and different user groups. Residents preferred an alarm-based tool but were also keen on a design which incorporated ideas such as a dashboard, an

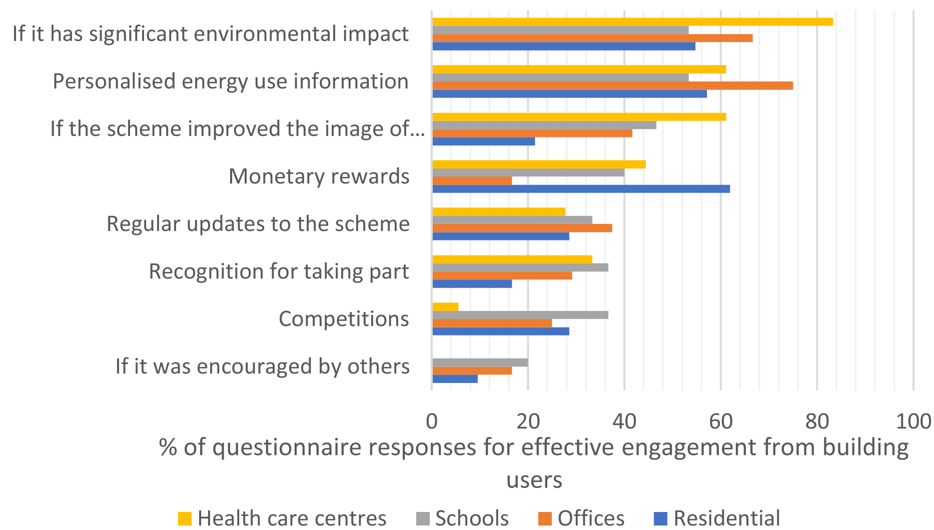


**Fig. 3.** Motivation towards engagement with ICT-based intervention within buildings.

advisor and rewards. Facility managers within the residential buildings were keen on a feedback-based tool which could be used to run the building more efficiently.

Within the non-residential buildings a range of preferences were uncovered. In the Health Care Centres there was a preference for an energy dashboard and advisor which can display important information in an easy and understandable format, with additional functions including setting alarms and being able to set building controls such as thermostats. Similarly, in office buildings the idea of a dashboard which could raise awareness and be linked to staff computers was preferred, alongside functions such as alarms, energy advice, feedback, competitions and a communication loop to report issues. Within schools there was a desire for gamification elements to be included so that rewards and competitions could be supported in an attractive manner. A dashboard was preferred within schools with similar additional functions, including alarms and advice, which can support feedback on energy use, and which can be displayed on screens to inform students and staff. To meet all, or the majority of users' preferences, these workshops pointed to designing an ICT-based tool that could incorporate a number of different functions and which can be customised to the user's requirements, therefore encouraging sustained engagement.

## 5. Discussion & conclusion

The initial results above highlight a range of relevant themes on the potential of user engagement for developing ICT-based tools to promote energy efficiency in buildings. The results have also shown many of the complexities involved with developing an ICT-based behavioural change intervention, and how employing co-design principles can help to find solutions to such challenges.

Although this project includes a range of building types, the inefficient energy behaviours reported across all buildings were extremely similar. Commonalities were found relating to lighting use, inefficient HVAC control, and wasteful appliance use. However, substantial challenges exist around designing an app that can accommodate multiple building types, meter and data issues, alongside the variety of building users. Building users want energy-related information, ideally personalised to their specific location and use of the building, often down to room level. Yet the extent of energy monitoring data available varied massively across the pilot buildings, with many lacking sufficient levels to be incorporated into an ICT-based tool. The eTEACHER project is managing this issue by installing compatible monitoring equipment in each building, in several cases at a cost of tens of thousands of Euros. This monitoring data is being linked to a "What-if Analysis", generating specific recommendations based on the building-specific energy data, therefore allowing for "personalised" energy information via the eTEACHER tool. However, this approach to overcome diversity in metering and monitoring systems will not be viable for ICT-based interventions that aim for mass take-up for any building. This is particularly problematic given the interest identified in this study in personalised and relatable information within such interventions.

A lack of agency to change behaviours was another issue highlighted in this study. Many building users in the eTEACHER pilot buildings are restricted in altering their thermal environment, either physically through tamper-proof thermostats and radiator valves, or through uncertainties in knowing who to contact and how to easily report issues. Here, an ICT tool which allows users to report issues and see updates on actions by facility managers could allow people to feel more empowered within the building and more satisfied with their ability to instigate a change. It has been previously shown in workplace environments that staff may be more 'forgiving' of discomfort if they are at least informed of what is happening [56] and may in fact be more productive and satisfied in their roles if they perceive that they can control their environmental conditions [57]. Therefore, for ICT-based tools such as eTEACHER, enhancing participation by building users, and ensuring that their participation is beneficial to them, may have wider benefits beyond improving the functionality of the tool itself.

User engagement approaches were successfully employed to aid the development of the eTEACHER tool and soliciting views on the app's design. These included a desire for energy information which is short and to the point, but with "layers" so that some building users (particularly those in a building operational role) can achieve more detailed monitored data. A commonality across all building types was the desire for energy saving advice as well as building/room temperature data. The project found that although similarities are seen in the questionnaire data, the complexities of developing one tool for different building types and building users were often uncovered in greater detail when allowing building users to use their voice and share views through interactive workshops. The numbers attending are encouraging, as is the formation of feedback forums in each of the pilot buildings, but as the project develops, generating sustained engagement is a key challenge. Promising approaches to achieve this include collective action and dialogue [7] and framing engagement around intrinsic motivations (e.g. for health, comfort, contribution to social good) [58]. Thus, a framing that emphasises both comfort *and* acting together has real potential, especially when implemented utilising gamification (e.g. completing challenges) and making any financial savings visible and linked to personal preferences.

Finally, considering the interaction between engagement and behavioural issues, it is vital that engagement-based approaches that focus on behaviour change must be ‘fit for purpose’. For example, one of the main inefficiencies the project encountered was with regards to the use of heating, lighting and cooling in unused spaces. Whilst this could be pursued through reminders for behaviour change, there is perhaps greater potential through sensors and automated controls. In several cases, respondents highlighted the need for more fundamental changes, such as insulating the building fabric. This is likely in many cases to be a stronger solution to both thermal discomfort and use of personal heaters. However, a range of behaviours highlighted in this study are much more amenable to personal behaviour change, in particular, lighting and appliance use.

Overall, ICT-based interventions using gamification may be able to support more efficient use of energy in these situations, however, major technical and engagement-based challenges remain in seeking to develop a one-size fits all approach. User engagement to support the development of the eTEACHER tool has proven successful in highlighting these issues and co-creation of the tool has sown seeds for a group of engaged stakeholders to provide further feedback and support take-up. Whether this empowerment in the design process translates into empowerment to meaningfully influence building energy use remains an open question which requires further investigation of eTEACHER and similar apps in-use.

One-size fits all solutions, whilst challenging, will be necessary if such devices are to be scaled up and implemented across the wider building stock. This study does highlight however that where possible, user-centred design principles can be used for initial scoping exercises as prerequisites for larger funded projects in order to engage *and* empower building users in designing energy efficiency interventions which are more effective, beneficial and sustainable.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2020.101772.

## References

[1] J. Burgess, M. Nye, Re-materialising energy use through transparent monitoring systems, Energy Policy 36 (2008) 4454–4459.
[2] Bull, R., Irvine, K. N., Fleming, P. and Rieser, M. (2013). Are people the problem or the solution? A critical look at the rise of the smart/intelligent building and the role of ICT enabled engagement. ECEEE 2013 Summer Study – Rethink, Renew, Restart.
[3] B. Bedwell, C. Leygue, M. Goulden, D. McAuley, J. Colley, E. Ferguson, N. Banks, A. Spence, Apportioning energy consumption in the workplace: a review of issues in using metering data to motivate staff to save energy, Technol. Anal. Strateg. Manage. 26 (10) (2014) 1196–1211.
[4] L. Bastida, J.J. Cohen, A. Kollmann, A. Moya, J. Reichl, Exploring the role of ICT on household behavioural energy efficiency to mitigate global warming, Renew. Sustain. Energy Rev. 103 (2019) 455–462.
[5] M. Andor, K. Fels, Behavioral economics and energy conservation–a systematic review of non-price interventions and their causal effects, Ecol. Econ. 148 (2018) 178–210.
[6] N. Mogles, J. Padget, E. Gabe-Thomas, I. Walker, J. Lee, A computational model for designing energy behaviour change interventions, User Model, User-Adapt. Interact. 28 (2018) 1–34.
[7] R. Bull, K.B. Janda, Beyond feedback: introducing the ‘engagement gap’ in organizational energy management, Build. Res. Inform. 43 (3) (2018) 300–315.
[8] T. Hargreaves, Beyond energy feedback, Build. Res. Inform. 46 (3) (2018) 332–342.
[9] Lehrer, D., and Vasudev, J. (2010). Visualizing information to improve building performance: a study of expert users. UC Berkeley: Center for the Built Environment. Retrieved from https://escholarship.org/uc/item/4n08r2q2.
[10] Foster, D., Lawson, S., Wardman, J., Blythe, M. and Linehan, C. (2012), May. Watts in it for me?: design implications for implementing effective energy interventions in organisations. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 2357-2366). ACM.
[11] R. Burrows, H. Johnson, P. Johnson, Influencing Values, Attitudes and Behaviour via Interactive and Social-Media Technology: The Case of Energy Usage, University of Bath, Bath, U. K, Department of Computer Science, 2013.
[12] D. Crowley, E. Curry, J. Breslin, Leveraging Social Media and IoT to Bootstrap Smart Environments, Big Data and Internet of Things: A Roadmap for Smart Environments, Springer International Publishing, 2014, pp. 379–399.
[13] K.B. Janda, Building communities and social potential: between and beyond organizations and individuals in commercial properties, Energy Policy. 67 (2014) 48–55.
[14] M. Moezzi, K. Janda, From ‘if only’ to ‘social potential’ in schemes to reduce building energy use, Energy Res. Soc. Sci. 1 (2014) 30–40.
[15] S.C. Staddon, C. Cycil, M. Goulden, C. Leygue, A. Spence, Intervening to change behaviour and save energy in the workplace: a systematic review of available evidence, Energy Res. Soc. Sci. 17 (2016) 30–51.
[16] Lockton, D., Cain, R., Harrison, D., Giudice, S., Nicholson, L. and Jennings, P., (2011). Behaviour change at work: Empowering energy efficiency in the workplace through user-centred design. In Behaviour Energy and Climate Change (BECC) Conference, Washington DC, 2011. Retrieved from: https://escholarship.org/content/qt6ww5h5jm/qt6ww5h5jm.pdf.
[17] Morgan, E., Webb, L., Carter, K. and Goddard, N., (2018). Co-Designing a Device for Behaviour-Based Energy Reduction in a Large Organisation. Proceedings of the ACM on Human-Computer Interaction, 2(CSCW), pp.1-23.
[18] O.G. Santin, L. Itard, H. Visscher, The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock, Energy Build. 41 (11) (2009) 1223–1232.
[19] Z. Yu, B.C. Fung, F. Haghighat, H. Yoshino, E. Morofsky, A systematic procedure to study the influence of occupant behaviour on building energy consumption, Energy Build. 43 (6) (2011) 1409–1417.
[20] S. Wei, R. Jones, P. De Wilde, Driving factors for occupant-controlled space heating in residential buildings, Energy Build. 70 (2014) 36–44.
[21] N. Murtagh, B. Gatersleben, D. Uzzell, 20:60:20 – Differences in energy behaviour and conservation between and within households with electricity monitors, PLoS ONE 9 (3) (2014).
[22] T. Hargreaves, M. Nye, J. Burgess, Making energy visible: a qualitative field study of how householders interact with feedback from smart energy monitors, Energy Policy 38 (10) (2010) 6111–6119.
[23] K. Buchanan, R. Russo, B. Anderson, The question of energy reduction: the problem (s) with feedback, Energy Policy 77 (2015) 89–96.
[24] T. Hargreaves, M. Nye, J. Burgess, Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term, Energy Policy 52 (2013) 126–134.
[25] Wilson, G. T., Bhamra, T. and Lilley, D. (2010). Reducing domestic energy consumption: a user centred design approach. Knowledge Collaboration and Learning for Sustainable Innovation ERSCP-EMSU. Conference Delft, The Netherlands, 25th-29th October 2010, pp.200-222.
[26] Y. Riche, J. Dodge, R. Metoyer, Studying always-on electricity feedback in the home, Home Eco Behav. (2010) 10–14.
[27] Weiss, M., Mattern, F. and Beckel, C. (2013). Smart Energy Consumption Feedback – Connecting Smartphones to Smart Meters, ERCIM News [online] available at: < https://ercimnews.ercim.eu/en92/special/smart-energy-consumption-feedback–connecting-smartphones-to-smartmeters > .
[28] N. Murtagh, M. Nati, W.R. Headley, B. Gatersleben, A. Gluhak, M.A. Imran, D. Uzzell, Individual energy use and feedback in an office setting: a field trial, Energy Policy 62 (2013) 717–728.
[29] M. Mulville, K. Jones, G. Huebner, The potential for energy reduction in UK commercial offices through effective management and behaviour change, Architect. Engi. Design Manage. 10 (1–2) (2014) 79–90.
[30] S.N. Timm, B.N. Deal, Effective or ephemeral? The role of energy information dashboards in changing occupant energy behaviours, Energy Res. Sci. 19 (2016) 11–20.
[31] DECC. (2018). CarbonCulture at DECC, [online] Available at: http://research.carbonculture.net/decc-report2012/category/discussion/.
[32] Y. Parag, K. Janda, More than filler: middle actors and socio-technical change in the energy system from the “middle-out”, Energy Res. Soc. Sci. 3 (2014) 102–112.
[33] U. Ritterfeld, M. Cody, P.A. Vorderer, Serious Games: Mechanisms and Effects, Routledge, New York, 2009.
[34] S. Deterding, M. Sicart, L. Nacke, K. O'Hara, D. Dixon, Gamification: using game design elements in non-gaming contexts. Extended abstracts on human factors, Comput. Syst. (2011).
[35] Grossberg, F., Wolfson, M., Mazur-Stommen, S., Farley, K. and Nadel, S. (2015). Gamified Energy Efficiency Programs. ACEE, Report Number B1501.
[36] D. Johnson, E. Horton, R. Mulcahy, M. Foth, Gamification and serious games within domain of energy consumption: systematic review, Renew. Sustain. Energy Rev. 73 (2017) 249–264.
[37] Banerjee A. and Horn, M. S. (2014). Ghost hunter: Parents and children playing

together to learn about energy consumption. In: Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction, pp. 267-274.

[38] P.W. de Vries, E. Knol, Serious gaming as a means to change adolescents' attitudes towards saving energy: preliminary results from the EnerCities case, EDEN Annu. Conf. 2011 (2011) 1–5.

[39] D. Geeleen, D. Keyson, S. Boess, H. Brezet, Exploring the use of a game to stimulate energy saving in households, J. Design Res. 10 (2012) 102–120.

[40] G. Wood, D. van der Horst, R. Day, A.G. Bakaoukas, P. Petridis, S. Liu, L. Jalil, M. Gaterell, E. Smithson, J. Barnham, D. Harvey, B. Yang, C. Pisithpunth, Serious games for energy social science research, Technol. Anal. Strategic Manage. 26 (10) (2014) 1212–1227.

[41] M. Senbel, V.D. Ngo, E. Blair, Social mobilization of climate change: University students conserving energy through multiple pathways for peer engagement, J. Environ. Psychol. 38 (2014) 84–93.

[42] Michie, S., Van Stralen, M.M. and West, R. (2014). The Behaviour Change Wheel: A guide to designing interventions. [Online] Available at: http://www.behaviourchangewheel.com [Accessed on 30th January 2017].

[43] Mankoff, J, Matthews, D, Fussell, S.R, and Johnson, M. (2007). Leveraging social networks to motivate individuals to reduce their ecological footprints. 2007 40th Annual Hawaii International Conference on System Sciences (HICSS'07).

[44] R. Bull, M. Lemon, D. Everitt, G. Stuart, Moving beyond feedback: energy behaviour and local engagement in the United Kingdom, Energy Res. Soc. Sci. 8 (2015) 32–40.

[45] Robinson, L. (2011). How to Design a Change Programme: The Changeology Process. [Online] Available at: http://enablingchange.com.au/enabling_change_process.pdf [Accessed on 23rd March 2017].

[46] G. Wallenborn, M. Orsini, J. Vanhaverbeke, Household appropriation of electricity monitors, Int. J. Consum. Stud. 35 (2) (2011) 146–152.

[47] E.L. Larson, S.J. Patel, D. Evans, L. Saiman, Feedback as a strategy to change behaviour: the devil is in the details, J. Eval. Clin. Pract. 19 (2) (2013) 230–234.

[48] S.M. Christina, A. Dainty, K. Daniels, P. Waterson, How organisational behaviour and attitudes can impact building energy use in the UK retail environment: a theoretical framework, Architect. Eng. Design Manage. 10 (1–2) (2014).

[49] L. Yardley, B.J. Spring, H. Riper, L.G. Morrison, D.H. Crane, K. Curtis, G.C. Merchant, F. Naughton, A. Blandford, Understanding and promoting effective engagement with digital behaviour change interventions, Am. J. Prevent. Med. 51 (5) (2016) 833–842.

[50] S.S. Van Dam, C.A. Bakker, J.D.M. Van Hal, Home energy monitors: impact over the medium-term, Build. Res. Inform. 38 (5) (2010) 458–469.

[51] A. Khosrowpour, Y. Xie, J.E. Taylor, Y. Hong, One size does not fit all: establishing the need for targeted eco-feedback, Appl. Energy 184 (2016) 523–530.

[52] T. Tang, Towards Sustainable Use: Design Behaviour Intervention to Reduce Household Environment Impact, University of Loughborough, 2010.

[53] A.H. McMakin, E.L. Malone, R.E. Lundgren, Motivating residents to conserve energy without financial incentives, Environ. Behav. 34 (6) (2002) 848–863.

[54] F. Lossin, A. Loder, T. Staake, Energy information for behavioral change, Comput. Sci. Res. Dev. 31 (3) (2016) 149–155.

[55] P. Inyim, M. Batouli, M.P. Reyes, T. Carmenate, L. Bobadilla, A. Mostafavi, A smartphone application for personalised and multi-method interventions toward energy saving in buildings, Sustainability 10 (6) (2018).

[56] A. Leaman, Dissatisfaction and office productivity, Facilities 13 (2) (1995) 3–19.

[57] N. Oseland, P. Bartlett, Improving Office Productivity: A guide for Business and Facilities Managers, Longman, Singapore, 1999.

[58] T. Crompton, Common Cause: The case for working with our cultural values, WWF, London, 2010.