From discovering to delivering: A critical reflection on eco-feedback, application design, and participatory research in the United Kingdom

Abstract

The area of Eco-Feedback has received significant attention in recent years. Whilst there have been increasing calls to move 'beyond feedback' and consider the wider social, organisational and cultural context that feedback sits within, the involvement of community members in the design process of eco-feedback applications, known as co-design, has been limited. This study addresses that research gap through working collaboratively with community members to develop an accessible eco-feedback interface. First, we conducted an online survey questionnaire with 151 respondents with distinct socio-economic characteristics and environmental knowledge to get insights into their preferences about different aspects of the eco-feedback interface. Secondly, based on the survey findings, 20 community members living in Nottingham, UK, worked collaboratively to develop interface design proposals. Finally, the design of the eco-feedback interface was finalised based on the community interface prototypes and suggestions. The developed interface contains multiple information panels with options for expanding to gain deeper levels of information and a community space allowing for community interactions and sharing of information and actions. This research sheds new light on the challenges of utilising co-design principles to build eco-feedback interfaces. Specifically, we highlight the potential for interactions between community members during the design stages to allow for the generation of innovative ideas (e.g. Integration of third-party applications) moving the interface beyond feedback leading to greater adoption and energy savings.

Keywords: Eco-feedback, energy sustainability, co-design, green ICT.

1. Introduction

The UK residential sector consumes approximately 27% of the country's total energy and emits around 20% of its CO_2 [1]. For this reason, the UK government has implemented a wide range of measures in this sector towards meeting its CO_2 emission targets. Whilst the majority of interventions have revolved around improving the thermal quality of the building envelope (e.g. retrofit), promoting pro-environmental behaviours has received increasing attention in recent years [2]. Indeed, research has found that changes in household behaviour can lead to 5-15 % savings in energy use [3].

Energy behavioural change interventions can be broadly classified into two categories; informational and structural [4]. Informational interventions, which are the most commonly discussed in the

literature, concentrate on tackling the motivational determinants of behavioural change. In particular, they are designed to alter people's knowledge, perceptions, and norms while raising their awareness [5]. Informational strategies can be further categorised into feedback, prompting, commitment, and goal setting. However, often two or more sub-categories are combined to allow an effective implementation (e.g. feedback and goal setting) [6].

One of the informational feedback approaches that have proliferated in recent years, due to advancements in information communication technology (ICT), is Eco-feedback. Due to their monitoring capabilities, Eco-feedback systems provide occupants with useful information about their past and current energy usage patterns with different levels of temporal granularity (e.g. hourly consumption of lighting) [7]. These have the potential to reduce household energy consumption [8–11]. However, existing Eco-Feedback systems concentrate largely on individual households despite the fact that research has shown that fostering a sense of community[1] is key to sustaining long-term behaviour change [12,13]. Of course, some studies have leveraged social techniques such as competition, comparison, collaboration, and social interactions in their Eco-feedback systems [14]. Again, this group of studies relies on the involvement of community members mainly in the implementation stages to test and improve a given Eco-feedback system but not in the actual design process. The involvement of stakeholders and end-users in the design stages of a service or product they might use in the future is referred to as co-design or participatory design [15]. While co-design principles have been widely adopted in different fields of study (e.g. urban planning) to increase public participation, they have not fully been considered in the design of eco-feedback systems. As designers and developers operate under certain assumptions, it is more often than not the perspectives of end-users are overlooked if they are not part of the design process [16]. In the context of community-based eco-feedback, not involving community members in the design stages may lead to the development of inaccessible eco-feedback systems that do not meet their needs and expectations. Subsequently, such systems would struggle to sustain the community engagement in pro-environmental behaviours in the long-term. This explains why there have been increasing calls to move 'beyond feedback' and consider the wider social, organisational and cultural contexts that feedback sits within [17,18].

Arnstein's ladder of participation [19] (see figure 1) is a helpful framework within which to understand stages of participation. At the bottom of her ladder is non-participation, then information provision and consultation which are still predominantly one-way forms of communication. Consultation, for

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[1] A community is in the context of this study, refers to a group of people sharing a sense of place located in a given geographical area such as neighbourhood, town, village, or city. This group of people could share communalities such as culture, religion, values, identity, and interests[66].

example, is still typically a relatively passive process which asks for people's opinions but does not necessarily engage them in the debate. Participation, noted Arnstein, should not be considered an 'add-on' but rather a set of steps to increased participation, partnership and ultimately, empowerment. Participation is normally used to refer to processes which allow people to participate in a decision by putting forward their views verbally whereas engagement goes further, suggesting an innovative and interactive, two-way process of discussion and dialogue (i.e. deliberation) to ensure that people's views inform a decision, alongside those of the expert and/or decision-maker. Therefore participation should be an innovative and interactive two-way dialogue that takes into account people's views in the decision-making process this emphasis on participation is echoed by [20], who notes that first, democracy is increased as all citizens have a right to participate and be represented in environmental decision making; second, non-experts are often more attuned to the ethical issues of a situation; and third, greater acceptance can often be achieved by involving all those affected by the particular situation. A fourth, and often overlooked benefit, is that processes of public engagement can create ideal conditions for social learning which can lead to varying degrees of behaviour change [21,22]. Thus, engaging the public may result in lowering people's resistance to engaging in pro-environmental behaviour [23].
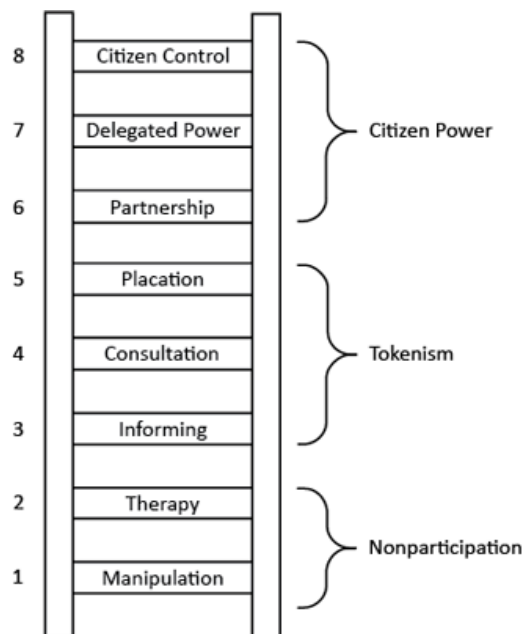

Figure 1. Arnstein's participation ladder retrieved from [19]

In response to the lack of participatory initiatives in the design process of eco-feedback applications, this research focuses on developing an accessible eco-feedback interface through a co-design

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approach involving the study researchers, Nottingham city community members, and energy experts in its design process. This work is related to the Nottingham Remourban future cities demonstrator project which is supported by Horizon 2020 [20]. Specifically, our study aligns with one of the Remourban objectives consisting of developing and restructuring technologies to promote citizen engagement. This is the rationale for selecting Nottingham as a case study. However, to frame the participatory process and ensure its effectiveness, the study used a well-established co-design framework known as the double diamond framework that originated by the UK design council [25]. This framework is discussed in more depth in the methodology section.

As noted in the double diamond framework, it is necessary to explore the wider context of a given problem before embarking on co-design activities [15]. In the context of this study, it is important to gain insight into the wider end-users' preferences about the eco-feedback interface.

The following objectives have been set to meet the study aim:

1. To gain an insight into the end-users' preferences about the design, layout, and features of the eco-feedback interface while identifying barriers to their engagement in pro-environmental behaviour.

2. To work collaboratively with the local community to develop eco-feedback interface prototypes based on the findings of objective one.

3. To finalise the design of the eco-feedback interface based on the prototypes and suggestions from the local community.

The remainder of this paper is structured into six sections. First, Section 2 reviews the literature related to eco-feedback, whereas section 3, presents the research methodology. Section 4 analyses the research findings and section 5 addresses the implication of the study findings on the design of the community-based eco-feedback interface. Finally, section 6 concludes the paper while discussing future research opportunities.

2. Literature review

The area of Eco-Feedback has received increasing attention in recent years. This is because several eco-feedback applications have proven to be effective for advocating behavioural change and helping occupants reduce electricity consumption (up to 20%) [21]. Despite the lack of focus on community-

based Eco-feedback applications [22], research in this area concentrates on the determinants of participant engagement (e.g. competitions and comparisons), data visualisation, and the level of data disaggregation [23].

First, numerous studies suggest that introducing comparisons between community members in their eco-feedback systems help promote pro-environmental behaviour [14,24]. However, others [25,26] reported unsuccessful comparisons when participants have very little or no knowledge of their peers. Moreover, users often express privacy concerns about sharing their data (e.g. energy usage) with other community members [8]. Instead, they preferred self-evaluating their actual energy usage against their historical one.

Many scholars report a positive effect of social competition on occupants' engagement in energy-saving activities [9,27–29]. However, the level of acceptance of such measure by certain participants and the consistency of its effect in the long-term remains open for debate in the literature [30]. For example, [9] and [29] reported 32% and up to 55% of reduction in energy consumption, respectively, when they ranked the residents of student accommodations based on their energy usage. Other studies such as [31]; however, advised that participants who disliked competition believe that introducing competition hindered their collaboration with other community members to save energy. Despite these controversies, there is a consensus in the literature that coupling competition with reward leads to positive changes in the environmental attitude of community members but only in the short-term [4]. For instance, in a study conducted by [32], the authors achieved a 20% energy reduction in student accommodation when including a competition mechanism such as ranking. However, there was a sharp decline in the engagement of residents in energy-saving activities after the scheme was over.

Due to their data sharing, geolocation and social interaction capabilities, the majority of community-based Eco-feedback systems tend to exist in the form of a smartphone app [33], website [34], and/or integrated into a social platform [35]. While these technologies helped in promoting and triggering pro-environmental behaviour, research has shown that they can pose an obstacle especially to those with low ICT skills and/or who are privacy-conscious [36]. For example, [37] achieved a 26% reduction in energy consumption when linking their Eco-feedback system to Twitter to send users suggestions about their energy usage. Conversely, in the GoodDeeds project [38], participants who were new to social media and/ or had a bad experience with it refused to share their energy-related data/ saving activities on it. Instead, they preferred to know about the energy usage and saving actions of others through a newsfeed widget. Similar findings were reported by [14] who encountered community distrust concerns with regards their community message board. In particular, participants with high-

energy consumption were upset and felt that their privacy was violated when their data was shared. Part of the problem is a "one size fits all" approach of existing studies that tend to provide the same feedback and utilise the same technology to different segments who have distinct motivations and energy saving experiences [39]. This is also evident in the paucity of studies that compare the impact of different technologies (e.g. mobile app and social media) on the engagement levels of different community members.

In their research, [40] analysed 14 studies and concluded that there was no robust evidence to suggest that disaggregated energy feedback is more effective than the aggregated one. However, disaggregated energy feedback can be more impactful when participants are already motivated ("energy enthusiastic"). The findings of other scholars [41]; on the other hand, were in disagreement as they advised that energy savings made with disaggregated Eco-feedback systems were superior to when utilising the aggregated ones.

In light of the above, it is evident that the effect of different aspects of Eco-feedback on the end-users' participation in pro-environmental activities is reported inconsistently in the literature. This represents another motivation behind exploring the views and preferences of the wider audience about the features of the envisaged Eco-feedback interface and without making assumptions. This is while identifying any obstacles that prevent them from engaging in pro-environmental behaviour. In this regard, the nature of preferences and obstacles to explore has been informed by key themes identified from the analysis of the literature of eco-feedback. These themes are as follows: familiarity with ICT, Eco-feedback technology preferences, privacy, social interaction, and type of feedback.

3. Methodology

Owing to the participatory nature of this research, it is vital to engage different community members and project stakeholders in the collaborative knowledge building process alongside considering their views and preferences. Thus, our research design draws on the double diamond framework (figure 2), a well-established model for delivering participatory research [43]. The backbone of the double diamond framework lies in its emphasis on "divergent" and "convergent" thinking. Divergent thinking consists of gaining insights into the problem or subject matter from the wider audience, whereas convergent thinking consists of refining and narrowing down the generated insights and perspectives to produce an optimal solution [42]. As shown in figure 2 (above), this thinking process occurs twice in the double diamond framework resulting in four stages namely: discover, define, develop, and deliver. A combination of qualitative and quantitative research methods, including survey

questionnaire and participatory focus groups (workshops), were utilised. More details about each phase in relation to the undertaken study are discussed the below sub-sections.
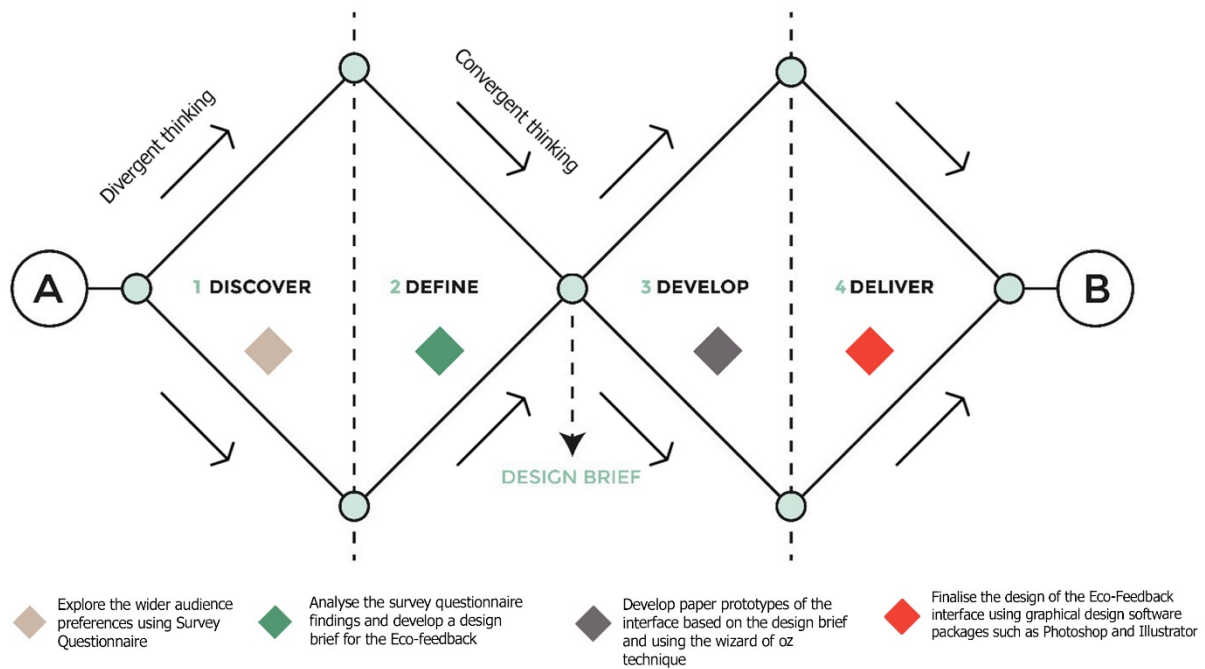

Figure 2. The Double Diamond framework, adapted from [42]

3.1. Phase 1: "Discover" the wider audience preferences and perceptions

In line with the double diamond framework, the "discover" stage comprised building insights into the preferences of the wider end users in the UK about the features of the potential eco-feedback interface. However, identifying any obstacles to their engagement in pro-environmental behaviour is also deemed necessary to reflect on and address in the design of the eco-feedback interface. There is a wide range of research methods that can be utilised in the "discover" stage such as interviews, focus groups, and survey questionnaires [42]. However, in this study, a survey questionnaire was adopted to enable reaching a wider audience within a short period and in an efficient manner. To help quantify the responses, the study's online survey questionnaire comprised mostly close-ended questions except for one open-ended question (see appendix A). The main questions in the survey revolved around the key themes identified in the literature. These are as follows: familiarity with ICT, Eco-feedback technology preferences, privacy, social interaction, and type of feedback. As there are disagreements in the eco-feedback literature about the relationship between these themes and the end-users' engagement in pro-environmental behaviour (section 3), getting an insight to the wider audience perspectives helped clarify the inconsistencies. In addition to the main questions, questions

related to the participants' general knowledge about environmental issues were added to the survey. According to [44], these type of questions acquaint participants with surveys covering energy sustainability and innovative technologies. Demographic questions were included in the survey to understand the characteristics of the sample and determine how responses may vary between different sub-groups (e.g. male and female). For more information on the survey questions, please refer to Appendix A.

Although the focus of this stage was to gain insights into the wider audience perceptions and preferences, the generalisability of findings has limitations [45]. It was challenging to ensure that every member of the population was given an equal chance to participate in the survey under the limited time and resources present in our study. For those reasons, we utilised a heterogeneity sampling, which is a non-probabilistic sampling technique. The heterogeneity sampling allows for multiple perspectives of participants to be presented. Furthermore, it is adequate when it is not possible to draw a random sample [46].

The survey was distributed to the public using the Jisc[2] service, which is a platform to promote participation in academic research studies [47]. Jisc sent the survey to different participants living in the UK using their existing databases and social media platforms [47]. To increase participation, the researchers introduced incentives in the form of Amazon vouchers. The survey responses have been analysed using descriptive and inferential statistical techniques such as Chi-square.

3.2. Phase 2: "Define" the design brief of the Eco-feedback user-interface

This phase entailed translating the wider audience preferences about the developed eco-feedback interface and obstacles facing their engagement in pro-environmental behaviour into a design brief. This helped the project stakeholders, including Nottingham city community members, develop interface prototypes in the subsequent phase. The brief should be clear and concise containing information about the aim/objective(s) of the eco-feedback interface, necessary contextual information about the project, target audience, and interface specifications. Whenever possible, the development of design specifications was based on different participants' suggestions to ensure a democratic participation process.

3.3. Phase 3: "Develop" Eco-feedback user-interface prototypes

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[2] Jisc is not-for-profit organisation that delivers digital solutions for UK higher education and research [47].

This stage consisted of collaboratively working with Nottingham city community members, energy experts, and the researchers to develop design prototypes of the eco-feedback interface based on the design brief created in phase 2. To attain this objective, two participatory workshops were held at Nottingham Trent University in May 2019 and were audio-recorded and transcribed. Twenty participants have taken part over both workshops (10 in each workshop), 14 of which were randomly recruited via the Jisc participation call portal under the condition they live in Nottingham. The remaining participants included the project researchers and three energy experts from Nottingham Energy Partnership (NEP)[3]. It is worth noting that the attendees had distinct demographic profiles and backgrounds. Furthermore, they self-reported different levels of knowledge of energy sustainability-related topic (see table 1 below).

Table 1. Profile of the focus groups' participants

	ID	Age	Education	Self-reported Knowledge of Similar topics		ID	Age	Education	Self-reported Knowledge of Similar topics
Focus Group 1	P1	35-44	Bachelor	Moderate	**Focus Group 2**	P11	45-54	Bachelor	Expert
	P2	25-34	MSc/PhD	Good		P12	25-34	MSc/PhD	Moderate
	P3	21-24	College	Moderate		P13	21-24	Bachelor	Little
	P4	35-44	Bachelor	Little		P14	35-44	MSc/PhD	Expert
	P5	<21	College	Moderate		P15	<21	College	Good
	P6	45-54	College	Little		P16	21-24	Bachelor	Good
	P7	55-64	Bachelor	Expert		P17	24-34	College	Little
	P8	25-34	MSc/PhD	Very Good		P18	35-44	Bachelor	Very Good
	P9 (PI)	25-34	MSc/PhD	Very Good		P9 (PI)	25-34	MSc/PhD	Very Good
	P10 (RA)	25-34	Bachelor	Good		P10 (RA)	25-34	Bachelor	Good

Note: PI (Principle investigator)/ Ra (Research assistant)

To maximise the number of generated interface prototypes within the study limited time, the two participatory focus groups were purposefully designed to be independent of each other. More precisely, the participants of each workshop have undertaken similar tasks with the same design brief. Following the double diamond framework, the first task consisted of delivering a presentation by the

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[3] Nottingham Energy partnership is an independent fuel poverty charity and home improvement agency established in 1998. In 2014, they have received the Queen's Award for climate change for successfully delivering key projects around tackling fuel poverty and reducing CO2 emission such as REMOURBAN [67].

principal investigator covering the elements in the **design brief** (see phase 2) in more depth. Following that, participants performed the below actions iteratively:

(1) Developed paper prototypes of the user-interface using different stationery items such as sticky notes. To allow an iterative design process with short releases, common community-based Eco-feedback interface elements such as energy consumption graphs, 2D/3D maps, weather widget, and buttons, were provided for the participants.

(2) Evaluated the paper prototypes using peer-discussions coupled with the wizard of Oz prototyping technique [48]. This technique permits users to explore the design and test the usability of the eco-feedback interface prototypes without the need for any computer programming to be conducted. For example, if users are testing the usability of the application menu, they can 'pretend click' on the application menu icon and mimic the reaction of the application by showing another paper panel that contains elements such as user profile, settings, logout, etc.

(3) After the focus groups' participants evaluated the produced prototypes, they were required to improve them while considering any ideas/suggestions from the peer-discussions.

3.4. Phase 4: "Deliver": Finalising the design of the community-based eco-feedback user-interface

Following the development of several interface prototypes and the generation of new ideas/ suggestions in the participatory workshops, this phase involved the development of a consensual community-based eco-feedback interface. To attain this objective, the researchers carefully examined the generated interface prototypes and the focus groups' transcripts. In this respect, similarities and difference between the prototypes were identified. After that, suggestions/ideas that were discussed in the focus groups but do not exist in the interface prototypes were considered. Based on that, a combination of well-known graphics computer applications such as Photoshop, InDesign, and illustrator was utilised to develop the final community based eco-feedback interface design.

4. Findings and discussion

4.1. Findings of phase 1

This sub-section discusses in detail the preferences of the wider audience regarding the developed eco-feedback interface through the analysis of the survey questionnaire findings. However, this is preceded by an analysis of the socio-economic characteristics of the participants and their degree of environmental knowledge.
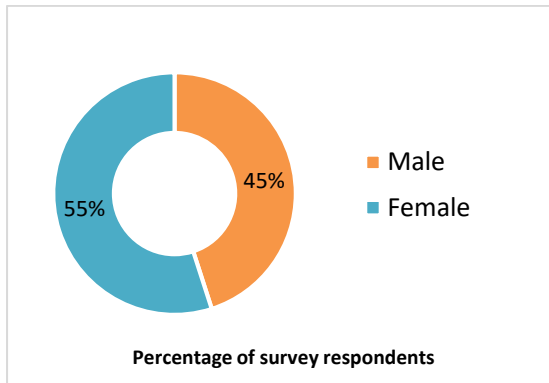
4.1.1. Sample characteristics

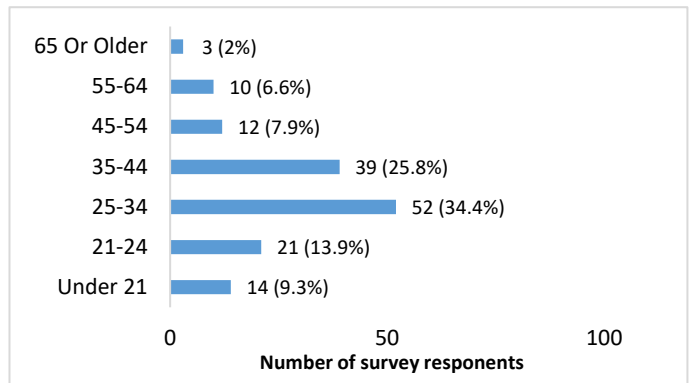**Figure 3**. Gender distribution of the survey respondents

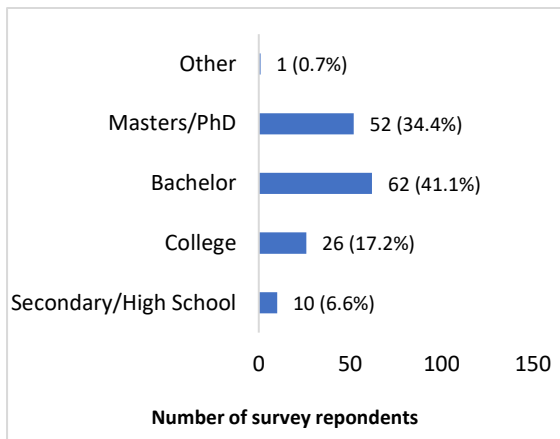**Figure 4**. Age distribution of the survey respondents

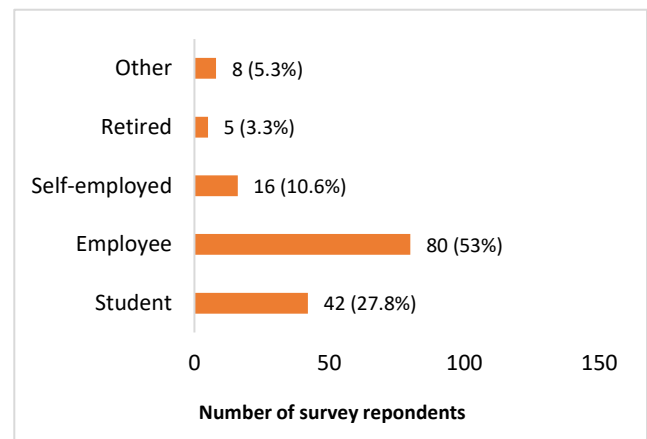**Figure 5.** Educational profile of the survey participants

Figure 6. Employment status of the survey respondents

Although the ideal of sample representativeness is an important aspect of a rigorous survey design as noted by [49], it was difficult to obtain a fully representative sample of the whole UK population). Therefore, the survey sample is unlikely to be fully representative of the wider population on important socio-demographic characteristics such as age, gender, and educational attainment profile. However, as indicated in section 3.1, the main objective of conducting this survey questionnaire was to obtain a broad spectrum of ideas and opinions rather than directly representing people's views to make generalisations.

151 participants with various socio-economic characteristics, as shown in the figures 3-6, filled the survey questionnaire. Overall, there was a good distribution between the proportion of male (45%) and female respondents (55%) as shown in figure 3. However, 60.2% of the surveyees were aged

between 25 and 44, whereas 14.2% had 45-64 years (figure 4). This could be attributed to the fact that the survey was mainly diffused through social media and networks, which are often used by younger groups. Regarding their level of education, the majority of participants possess at least a University degree. In particular, 41.1% of them had a bachelor degree, 34.4% achieved an MSc or PhD, 17.2% have a college qualification, and 6.6% obtained a secondary/high school-related qualification (figure 5). Finally, (53%) were employed, whereas 27.8% were students and 3.3% were retired (figure 6).

4.1.2. Environmental Knowledge and awareness of the participants and their familiarity with ICT

As discussed previously, the survey questionnaire included questions that helped identify the environmental knowledge and awareness of the respondents and which covered the following areas:

- General knowledge about residential energy saving
- Responsibility for energy saving
- Reasons for the lack of engagement in pro-environmental behaviour
- Recent actions made to improve energy efficiency

Overall, as shown in figure 7, 51% of the respondents claimed to have moderate knowledge about home energy saving and 33.8% said to have a good to very good knowledge on the topic. Further investigation using a Chi-square test confirmed that people with MSc/PhD education are more likely to be very knowledgeable about domestic energy-saving x^2(11.089, p< .01). As expected and in line with the findings of [50], the vast majority of respondents (83%) felt responsible for saving energy (figure 8). After conducting a Chis-square test, it was found that people claiming to have a good/ very good knowledge are more likely to feel responsible about reducing their energy usage x^2(6.275, p< .012) which was in agreement with the findings of [51].

Interestingly, as illustrated in figure 9, respondents attributed the low engagement of households in pro-environmental behaviour primarily to the lack of information on energy savings (33.4% of responses) and to time and availability to a lesser degree (25.1% of responses). Based on that, the developed eco-feedback system should focus on providing useful information and suggestions on domestic energy saving. This is while opting for a simple, clear, and straightforward user-interface as advised by a recent study, which found a significant negative correlation between the energy-saving levels of busy households and the complexity of eco-feedback systems' user-interface [52].

Regarding actions taken recently to improve energy efficiency, the majority of the respondents reported actions revolved around *switching to energy-efficient LED lighting* and *improving heating*

controls (e.g. heating only occupied rooms) as depicted in figure 10. On the other hand, few respondents reported actions such as *upgrading to efficient appliances and boiler*. However, none of the revealed actions covered initiatives at the community level such as neighbourhood renewable energy networks. According to [53], this could be attributed to the fact that a large number of environmental campaigns advocate individual instead of collective environmental change which supports the development of our community-based eco-feedback application.

As expected from analysing the age profile of the surveyees, 74.8% of them were very comfortable with ICT technology, whereas only 2.6% were not comfortable (figure 11). However, a Chi-square test advised no significant relationship between age and familiarity with ICT.
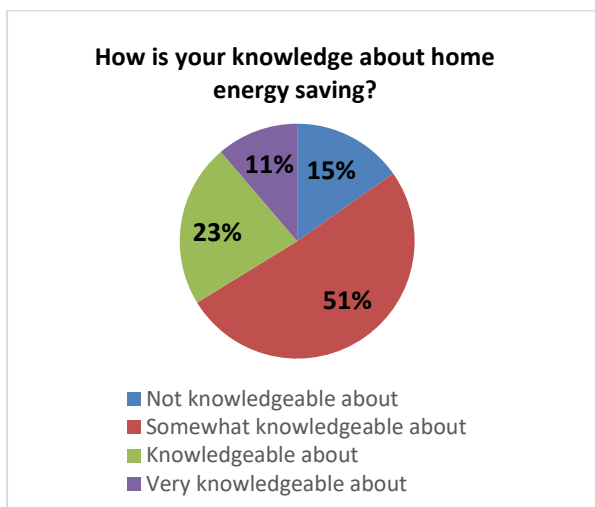

Figure 7. The respondents' Self-reported knowledge about energy saving
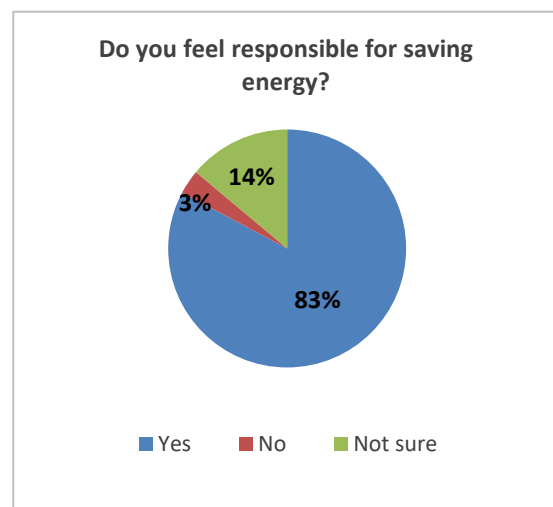

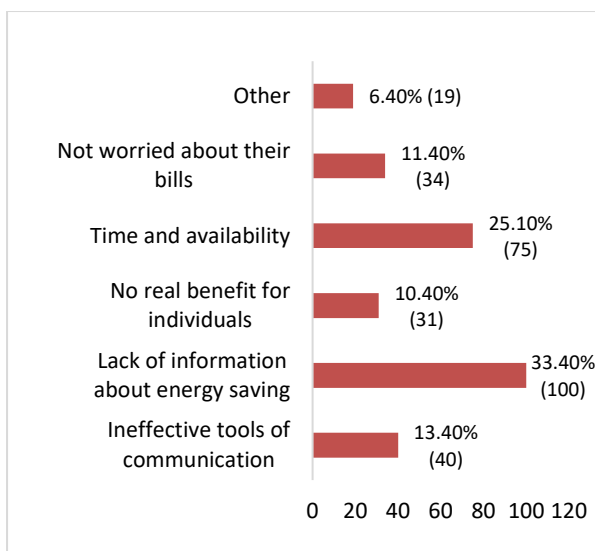**Figure 8**. The participants' degree of responsibility for saving energy

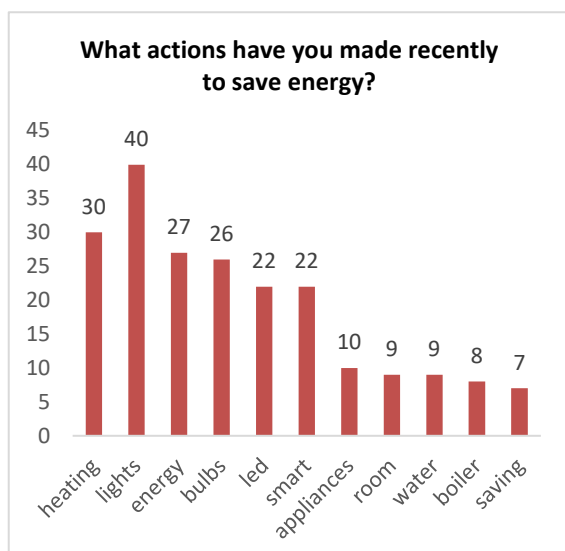**Figure 9.** Surveyees' opinions about the lack of engagement in pro-environmental behaviour

Figure 10. The word frequency in the household answers about their recent actions to save energy.
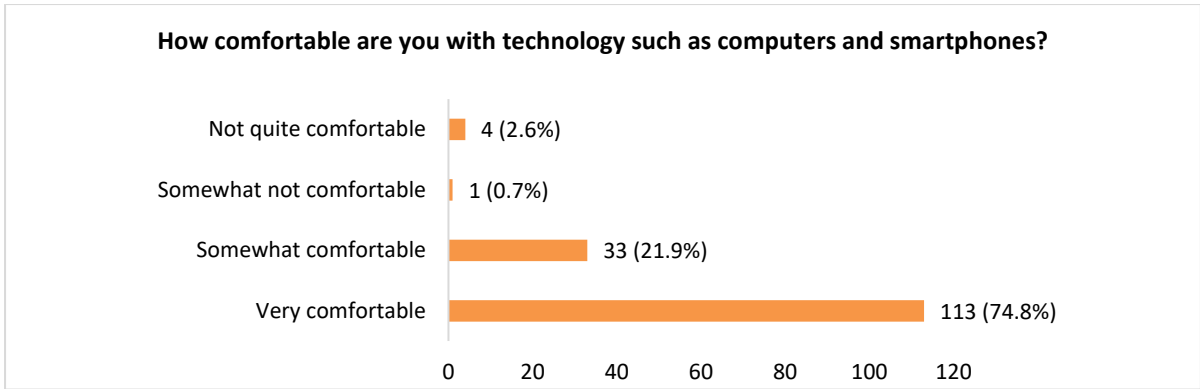
How comfortable are you with technology such as computers and smartphones?

- Not quite comfortable: 4 (2.6%)
- Somewhat not comfortable: 1 (0.7%)
- Somewhat comfortable: 33 (21.9%)
- Very comfortable: 113 (74.8%)

Figure 11. The level of familiarity of participants with Information technology.

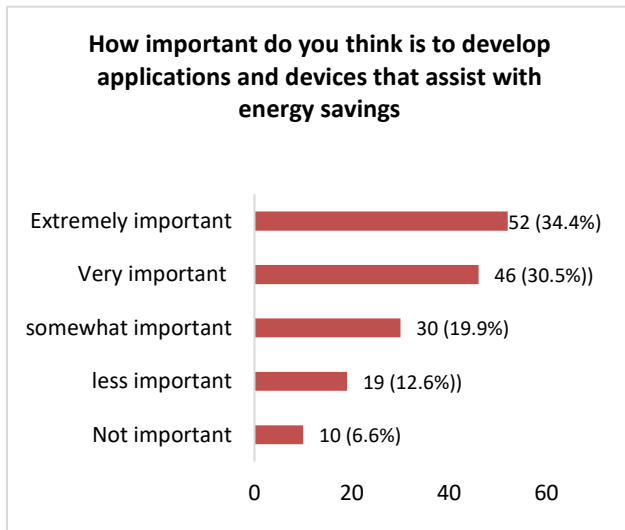### 4.1.3. Participants eco-feedback preferences and perception

How important do you think is to develop applications and devices that assist with energy savings

- Extremely important: 52 (34.4%)
- Very important: 46 (30.5%))
- somewhat important: 30 (19.9%)
- less important: 19 (12.6%))
- Not important: 10 (6.6%)

Figure 12. Participants' opinions about developing applications to assist domestic energy saving

We are developing a software to help the community reduce their home energy consumption. What would be your preferred software version? (*Check all that apply*)

- Other: 1.70% 4
- PC/Laptop application: 12.60% 29
- Smartphone application: 51.10% 118
- Integrated in Social media such as Facebook and…: 9.10% 21
- Website version: 25.50% 59
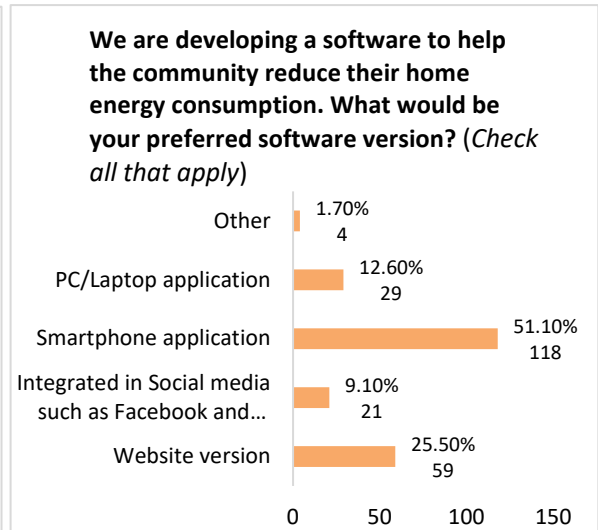
Figure 13. The preferred eco-feedback application by the survey respondents

What are your thoughts about sharing energy consumption data anonymously with the community members? (please note that your personal information will NOT be shared)

- Other: 0.70% (1)
- Neither: 9.30% (14)
- I prefer to share and know: 53% (80)
- I prefer to know only: 25.80% (39)
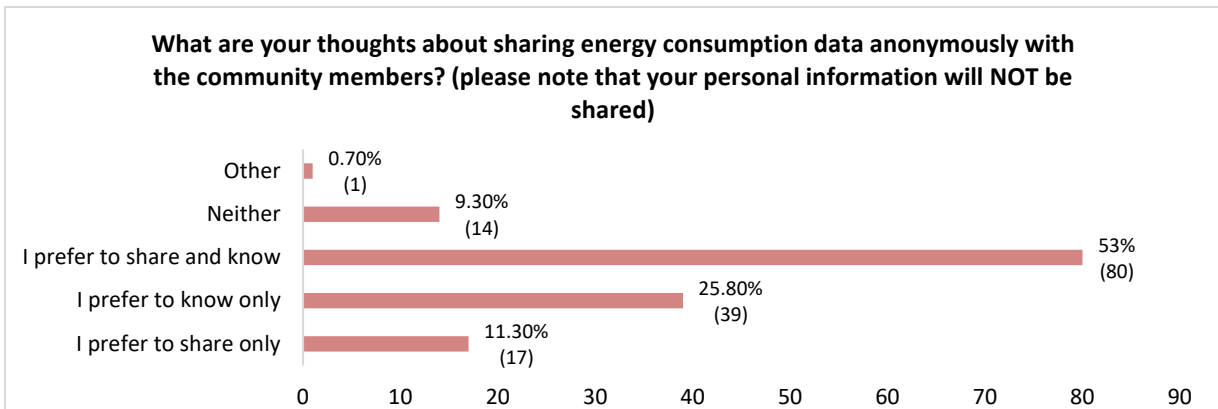- I prefer to share only: 11.30% (17)

Figure 14. The respondents' opinions about the sharing of data with other community members

The analysis of the previous sub-section has shown that the survey respondents, in general, had a moderate to a very good environmental awareness, although there was a clear lack of community sense in their reported actions. This was also reflected in their belief in the importance of developing software and hardware to promote pro-environmental behaviour. In this respect, 65% believed that it is extremely important to develop applications and devices to help them save energy (figure 12). After expressing our intention to develop a community based eco-feedback system, approximately 51% gravitated towards a smartphone version, whereas only 9.1% of them preferred a social media plugin (see figure 13). This could be an indication of privacy concerns amongst respondents, even though 74.8% of the respondents were very comfortable with ICT and familiar with social media platforms given their age profile. As noted by [14,38,54], being familiar with social media does not necessarily lead to acceptance of sharing information about energy consumption with others.

Since privacy and data sharing are key aspects to consider when designing a community-based eco-feedback system, respondents were asked whether they preferred to share data **anonymously** with other community members. As depicted in figure 14 (above), More than half (53%) of the respondents did not mind sharing and knowing about others, whereas 9.3% preferred neither options. Following a Chi-Square test, it was found that people with a Bachelor degree or lower are more likely to resist sharing data x^2 (6.370, p< .05). Considering that low educational attainment proved to be correlated with low energy saving levels in many studies [55], it is important to incorporate features that help this group engage in energy-saving activities. This may include comparisons with the average energy usage of similar households (e.g. +30% above average).

Although there have been increasing calls to move beyond providing feedback, a large number of existing eco-feedback systems are confined to visualising the present and current usage of households without necessarily proving suggestions/tips to help them become more efficient users [56]. For this reason, our survey questionnaire measured the wider end-users' acceptance to receiving Eco-suggestions/tips including the ones from external sources such as videos and blogs. Overall, roughly 65% of the respondents preferred to receive Eco-suggestions, whereas 0.66% refused (figure 15 below). However, approximately 30% were open to suggestions but as long as they do not affect their comfort. This advises that the envisaged Eco-feedback system should be equipped with a multi-criteria optimisation model to allow the generation of eco-suggestions/tips without sacrificing users' comfort. In addition to the suggestions provided by our eco-feedback interface, 49% of the respondents believed that obtaining suggestions from external sources is extremely/ very important, whereas 26.5% thought it was somewhat important (figure 16). 24.5% of the participants; however, advised that this measure was not important/ not important at all. Following a cross-tabulation analysis, it was

found that 90% of this group were those who did not feel responsible/ not sure about saving energy. This could be an indication of their lack of awareness about pro-environmental behaviour. However, since the outcome of the Chi-Square test indicated that this association was not significant, more research is needed in that respect.

Apart from their acceptance of eco-suggestions, respondents did not have any particular preferences with regards the type of information that should be known and/or shared. First, the respondents preferred to know/share information about their electricity (42% of answers) and gas (36% of answers) as depicted in figure 17. The lower percentage of those who chosen to know/share information about their gas usage could be related to the non-presence of gas in their dwellings. Interestingly, 22% of the participants' answers revolved around knowing/sharing information about hot water consumption. Secondly, the respondents found both aggregate and disaggregate information equally important (figure 18). More precisely, 63.6% of respondents preferred to receive/share information about their aggregate energy usage, whereas roughly 58% on average were keen on knowing and sharing disaggregate information. This includes information about their heating system, home appliances, and home energy rating. This suggests that the Eco-feedback interface should offer end-users both aggregate and disaggregate information while providing a certain degree of flexibility to allow them to be in control of the desired level of detail to be known or shared with others in their community. Apart from that, 60.3% of the surveyees expressed an interest in sharing/knowing green actions. Interestingly, 5.3% of the participants requested other types of information. In this regard, 25.7% of this additional information included suggestions on real-time energy usage, whereas 74.3% of this additional information revolved around time-of-use tariffs such as when is cheaper to use electricity. Similar findings were reported by the UK citizens advice bureau [57] who surveyed 502 participants and found that poor information about time-of-use tariffs is one of the reasons behind 51% of the participants refusing/failing to successfully shift their demand. This indicates the importance of time-of-use tariffs related information in our Eco-feedback interface, although only 3.94% of the participants suggested it. Nevertheless, future users of the developed should be given the option to enable/disable information about time-of-use tariffs to ensure the preferences of certain groups are considered.

Finally, 45% of the respondents believe that ranking households based on their energy consumption would help them engage in energy-saving activities (see figure 19). On the other hand, 35.8% suggested that ranking should be coupled with a reward mechanism to be effective. Conversely, 20% perceived ranking as non-effective for promoting pro-environmental behaviour. After further investigation, it was found that people aged 25-34 are more likely to gravitate towards rewards x^2

(39.642, p< .01). These findings align with several studies in the literature suggesting that reward schemes can be effective when addressing the lack of engagement of the youth population in community and environmental activities [58]. In contrast to that, no significant associations have been found between the group that answered no to ranking and their socio-economic factors. Thus, more research is needed in that respect.
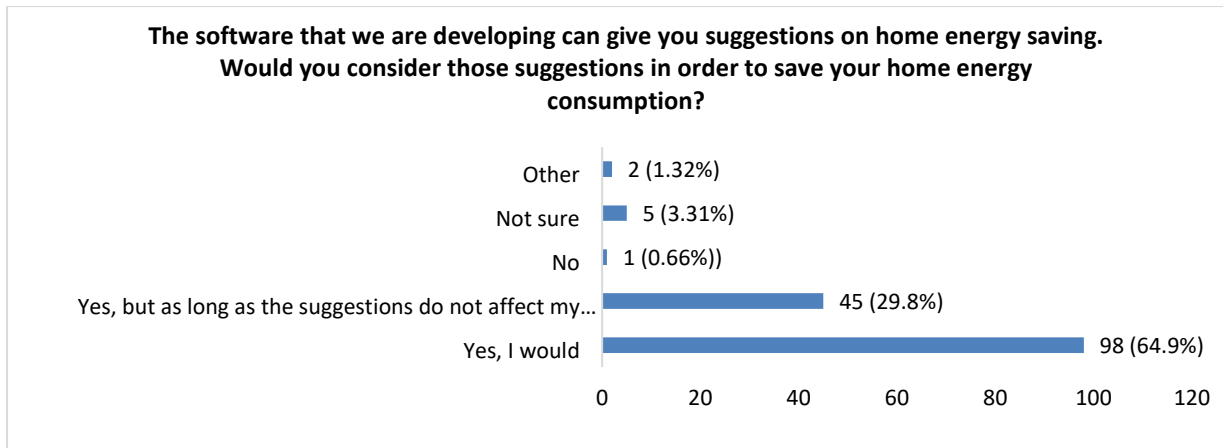
The software that we are developing can give you suggestions on home energy saving. Would you consider those suggestions in order to save your home energy consumption?

Other	2 (1.32%)
Not sure	5 (3.31%)
No	1 (0.66%))
Yes, but as long as the suggestions do not affect my…	45 (29.8%)
Yes, I would	98 (64.9%)

Figure 15. The survey participants' view on receiving suggestions on home energy saving

Receiving suggestions from external sources in forms such as videos and blogs

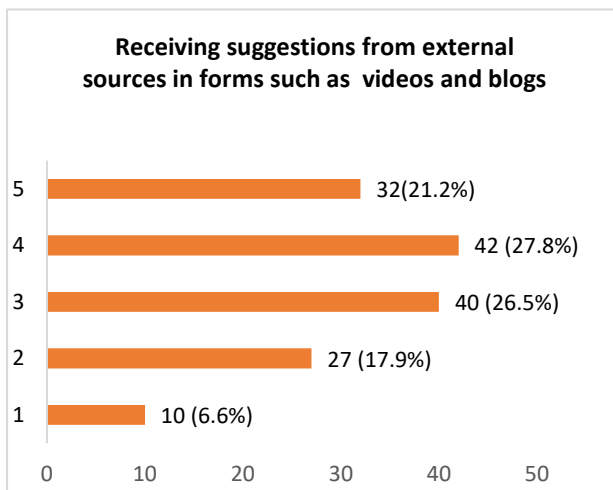|	
5	32(21.2%)
4	42 (27.8%)
3	40 (26.5%)
2	27 (17.9%)
1	10 (6.6%)

Figure 16. The surveyees views on the importance of including suggestions from external sources in forms such as videos and blogs (where 1 is the least important and 5 is the most important).
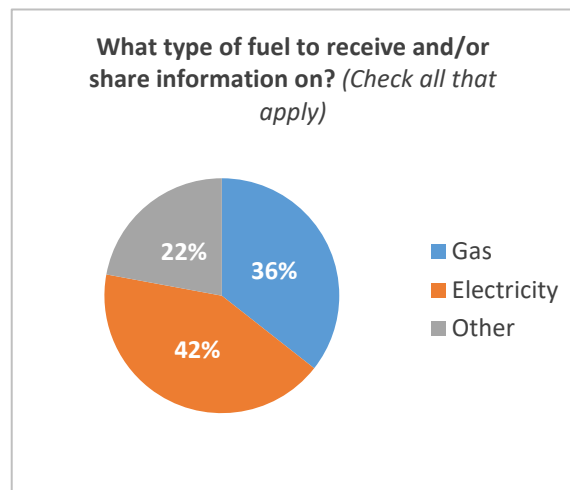
What type of fuel to receive and/or share information on? *(Check all that apply)*

Gas 36%
Electricity 42%
Other 22%

Figure 17. The surveyees' preferences about the type of fuel to receive/share information on

What types of information that you are willing to share/know? *(Check all that apply)*

- Other — 1.40% (8)
- Actions made to save energy consumption (e.g. changing old light bulbs to LED) — 16.10% (91)
- Your home energy rating (e.g. A+, C, D, etc…) — 15.90% (90)
- Information about your main home appliances (e.g. Fridge and Cooker) — 14.30% (81)
- Information about your heating system (e.g. Type of boiler) — 16.10% (91)
- Quantity of your energy usage in KWh (meter readings) — 17% (96)
- Cost of your energy usage — 19.10% (108)

Figure 18. Surveyees' preferences with regards information type to share/ know (multiple answer reported)

- Other — 5.30% (8)
- No, even if there is a reward — 0.70% (1)
- Yes, but only if there is a reward — 35.80% (54)
- No — 13.20% (20)
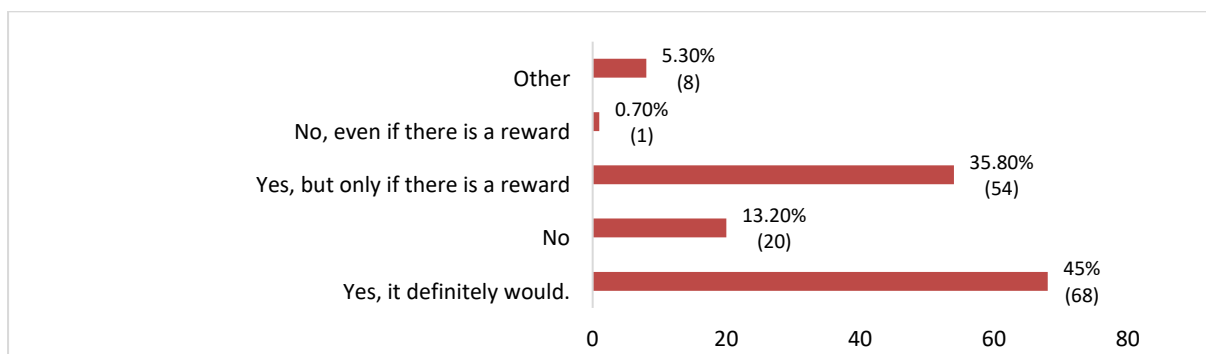- Yes, it definitely would. — 45% (68)

Figure 19. The survey respondents' views on the importance of ranking

4.2. Development of the Eco-feedback interface design brief (phase 2)

As indicated in section 3.2, a design brief was developed based on the analysis of the survey questionnaire results. This brief informed the workshops' participants in phase 3 about the aim and objectives of the project and guided them their design of the interface prototypes. Tables 2 and 3 illustrate the list of specifications issued to the workshop participants', where the second column represents the preferences of the survey respondents. Conversely, column 3 provides recommendations from the researchers based on the analysis of the survey questionnaire.

Table 2. Eco-feedback interface design specifications (part 1)

	Opinions of the survey respondents	Recommendations from the researchers based on the survey analysis
The version of the Eco-feedback interface	• 51.10% smartphone version • 25.5% web version • 12.6% pc/laptop version • 9.1% social media plugin	You should focus on producing a Smartphone version. Other versions are going to be developed in the future.
Data sharing with community members	• 53% preferred to know and share data with others • 9.3% did not want to know and share data with others	Users should be given an option to specify whether they would like to know and/or share data with others or not. To help those who chose not to know and share data engage in pro-environmental behaviour, measures including comparisons with the average energy usage of similar households, need to be developed.
Eco-suggestions/tips	• 65% wanted to receive eco suggestions/tip. • 29.8% wanted to receive eco-suggestions/tip but if they do not affect their comfort.	The developed Eco-feedback interface should provide users with Eco-suggestions/tips. As some users noted that they do not want the suggestions to affect their comfort, a future plan is to develop a multi-criteria optimisation model inside the interface.
Eco-suggestions/tips from external sources (e.g. videos and blogs)	• 49% believed that it is very / extremely important to receive suggestions from external sources • 24.5% believed that suggestions from external sources are not important.	Suggestions from external sources should be part of the developed Eco-feedback interface. Those who refused to receive suggestions/tips from external sources did not feel responsible/ were not sure about saving energy. Thus, we should develop features that raise their pro-environmental awareness.
Type of fuel to share and receive information about	• know/ share information about their electricity usage (42% of the answers) • know/ share information about their gas usage (36% of the answers) Share/know information about other fuel sources (22% of the answers). This was mainly about hot water consumption	Users should know and share information related to electricity, gas, and hot water consumption. However, they should have given the option to customise it.
Type of information to be known/shared	• Quantity of energy usage (17% of the responses) • Cost of used energy (19% of the answers) • Information about home appliances and heating system (30.4% of the answers) • Information about home energy rating (15.9% of the answers) • Actions made to save energy (16.1%)	Respondents found both aggregate and disaggregate information equally important. However, they should be allowed to adjust the type of information to be shared/known. Some respondents wanted information about off-peak energy tariffs while others wanted to obtain real-time energy feedback.

Table 3. Eco-feedback interface design specifications (part 2)

	Opinions of the survey respondents	Recommendations from the researchers based on the survey analysis
Ranking based on energy consumption	• Ranking would help promote domestic pro-environmental behaviour (45% of respondents) • Ranking would help promote domestic pro-environmental behaviour but only when there is a reward (35.80% of respondents) • Ranking would not help promote pro-environmental behaviour (13.2% of respondents)	Overall, there was a general acceptance of ranking by the wider audience. However, the ones aged between 25-34 are more likely to gravitate towards reward.

4.3. Findings of participatory workshops (Phase 3)

This section concentrates on the design rationale of the developed community-based eco-feedback interfaces. Furthermore, it sheds light on areas where participants expressed different opinions and beliefs.

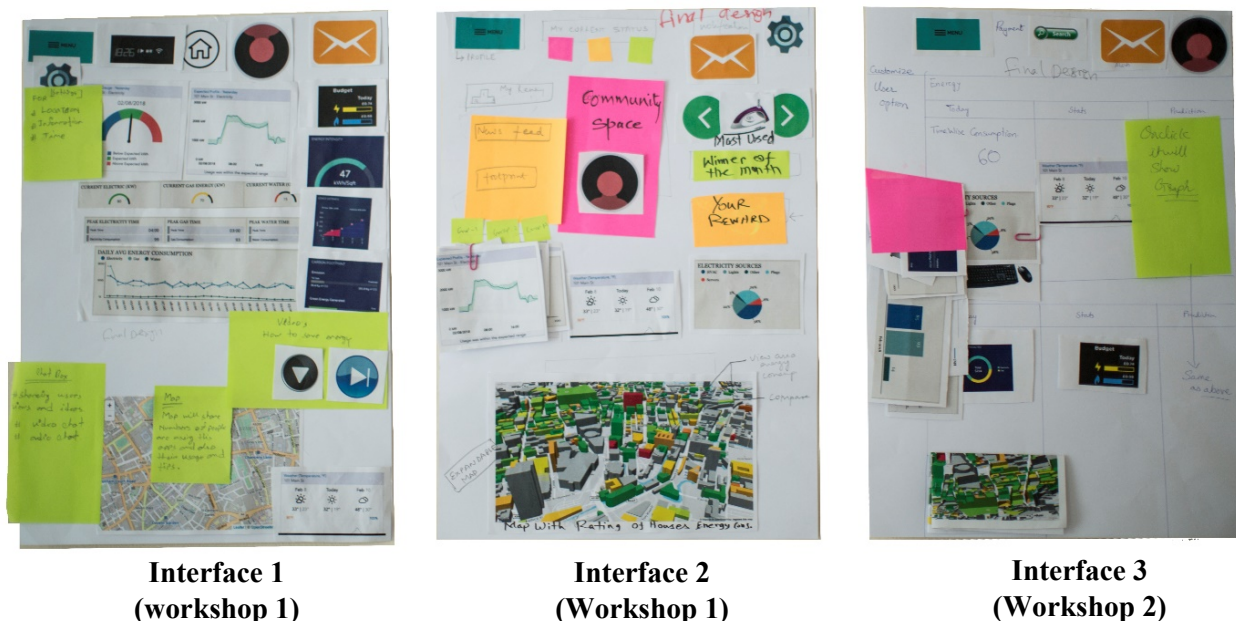### 4.3.1.   Interface layout, organisation, and customisability

| **Interface 1 (workshop 1)** | **Interface 2 (Workshop 1)** | **Interface 3 (Workshop 2)** |

Figure 20. The three designs developed by members of the community during the focus groups

Table 4. Layout organisation of each interface design

	Participants involved	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5
Interface 1	P1-P5	• Menu • Notification • Interface preferences • Digital clock	• Current aggregate energy consumption • Cost of aggregate energy usage • Comparison to the average energy user	• Disaggregate energy usage (historical and current)	• Eco-suggestions (external videos and links to energy-saving support schemes	•Energy performance of the neighbourhood
Interface 2	P6-P10	• Menu • Notification • Interface preferences • My current usage status	• Community interactions and competition (e.g. chat, newsfeed, ranking, etc.)	• Disaggregate energy usage (historical and current) • Predicted disaggregate energy consumption based on the weather forecast.	Energy performance of the neighbourhood	N/A
Interface 3	P11-P18, P9(PI), and P10 (RA)	• Menu • Notifications • Profile • Search bar • Payment feature	• Current aggregate energy consumption. • Comparison to the average energy user • Cost of aggregate energy usage	• Disaggregate energy usage (historical and current) • Predicted disaggregate energy consumption based on the weather forecast	Energy performance of the neighbourhood	N/A

Following the completion of the two focus groups, three interface designs have been developed through 12 design iterations (4 per design) as shown in figure 20. In the first workshop, the 10 participants (P1-P10) developed interfaces 1 and 2. On the other hand, the participants of workshop 2 (P11-P18 and P9&P10) produced only interface 3 because they preferred to work in one group instead of two groups of 5 as in workshop 1 (note that close-up images of each interface are included in Appendix B).

First, 75% of the participants preferred a **portrait** arrangement (figure 20). Similar findings were reported by [59] who suggested that 60% of non-game based app users prefer portrait orientation. As for the interface organisations, the participants of both workshops used the design brief and the printed interface elements such as menu button, energy consumption graphs, and maps, to create the layout of their interface prototypes. As depicted in figure 20, interfaces 2 and 3 were composed of 4 panels, whereas interface 1, had 5 panels. Nevertheless, participants who worked on interface 3 suggested that their interface should be fully customisable, "*We want to give users a feeling of their own, so they can customise the interface in the way that suits them.*" (P1)

In interface 1, panel 1 was allocated to the menu, notification, interface preferences, and a digital clock. Panel 2; however, comprised a status panel displaying the current energy consumption and cost

in addition to an indication of the user performance in relation to the average energy consumption in the area (e.g. low). Panel 3 contained disaggregate information about their current and historical energy consumption. Panel 4 of interface 1, encompassed external eco-suggestions in the form of videos on how to save energy and links to energy-saving support schemes. Finally, panel 5 comprised a map showing the energy usage of the area.

In contrast to the above, interface 2 contained 4 panels, where panel 1 shared similar items with the panel 1 of interfaces 1 and 3 such as allocated for menu, notifications, and interface settings. However, it included a unique feature "my current usage status" where the users get a hint on their energy performance in comparison to the average usage in the area in the form of a traffic light system (figure 20). Interestingly, the designers of interface 2 suggested that panel 2 should focus on community interactions and competition (e.g. chat, newsfeed, ranking, etc.). Like interface 1, the participants allocated panel 3 to detailed information about their historical and current usage. However, the designers of interface 2 also preferred to obtain an indication on their future energy usage based on the weather forecast. In this respect, P7 said," *I read somewhere that there are algorithms that predict the energy consumption of users. I really would like to see my estimated energy usage based on the weather forecast".* Finally, panel 4 was confined to showing the energy usage of the neighbourhood using maps.

From analysing table 4 and figure 20, it is evident that interface 3 share similarities with interface 2. One of the similarities is that panel 1 of each interface includes an application menu icon, notifications button, and profile button. However, participants working on interface 3 decided to include a search bar to browse through the content of the interface quickly. Moreover, they opted for a payment feature, which will be discussed in the coming sub-sections. Similarly, panel 2 of interface 3 encompassed the aggregate energy usage of the household and an indication of their performance in relation to the average energy usage in the area. In panel 3; however, provides detailed information about the households present and past energy usage. In panels 2 and 3, participants (P6-P10) placed particular emphasis on knowing their predicted aggregate and disaggregate energy consumption, correspondingly. In this respect, P8 added,

"So*, what we are going to give in panel 2 is the energy consumed today and then the prediction number. If I click on the predicted number in panel 2, panel 3 should show a detailed graph."*

Finally, the designers of interface 3 allocated panel 4 to visualising the energy consumption of the neighbourhood on a 2D/3D map.

4.3.2. Interface complexity and level of information detail

18 out of 20 participants recommended that the interfaces should be easy, enabling the user to readily and rapidly access distinct kinds of information. Their choice was ascribed to busyness and the degree of familiarity with ICT, which aligns with the findings of [52]. In this regard, a contributor (P2) added,

"I think people are quite busy and they would like something that would give them an idea on the flight and located in one place. If the interface is too complex, then it would be an obstacle for people who are not good with technology like my dad." (P2)

Similarly, 8 contributors expressed comparable opinions but proposed that the user should be in command of the level of information detail as stated the following statement,

"I *think that the initial interface should be very simple but if the user would like to know more, they can click on the relevant parts to get more information."* (P5)

The participant (P5) further added that users should also control the level of disaggregation in function of their preferences and energy-saving goals, "I think that all graphs should be located in one place and the *user should have the option of customising what type of graphs to be displayed because we have different personal preferences and energy-saving goals*." (P5)

On the one hand, the above statement contradicts many initiatives in the literature which concentrate on promoting disaggregation as a mean to motivate consumers to save energy and that pay little attention to their preferences. On the other hand, it reinforces the findings of [40] who advised that disaggregation is only more effective when participants are already motivated. Thus, there is a need for studies identifying the nature of the relationship between users' energy-saving goals and their preferences with regards the level of disaggregation.

4.3.3. Data sharing and privacy

Although the survey findings revealed that the majority of the surveyees preferred to share data and know about others, 3 participants expressed privacy concerns about sharing data with community members. More precisely, P13 produced the below declaration, believing that sharing energy consumption data would allow the public to begin formulating assumptions about a household lifestyle and socioeconomic status instead of concentrating on decreasing their energy use.

"To be fair, I don't like sharing. I find sharing my data with neighbours insane. Suppose that I consumed less energy than my next-door neighbours who has the same number of people and rooms. They could

wonder why I am using less energy, is it because I cannot afford the bills, or I am staying less at home? If they do, then they miss the whole purpose of this app." (P13)

Conversely, 4 participants thought that sharing data with others generates high expectations to save energy that can cause them stress and anxiety as P9 said, *"I have a reservation about people knowing that I am using high energy because that would make me feel guilty which could cause me stress and anxiety."* Similar findings were also reported by [14].

4.3.4. Relevance and type of geographical data visualisation

Following the above discussions on data sharing, the contributors suggested that geo-location data represents the main source of privacy concerns. Indeed, the group discussions have largely focused on aspects such as the necessity of geolocation data, type of maps, and level of aggregation. For instance, 5 participants did not only question the relevance of visualising energy information on a map but also found it unnecessary. Instead, they proposed evaluating their energy performance only against their social network (below statement), which is in line with the findings of [25,26].

"… sharing is fine but not to the point of clicking on the building and getting the information. I prefer to compare it against your contacts that you can add them to the application such as friends." (P8)

In contrast to the above, 8 participants believed that adopting geo-located data is indispensable for monitoring and tackling issues related to the engagement of community members in energy-saving activities as highlighted below,

"For me, it is good to see in your neighbourhood if people are interested and engaging. If no interactions, it means that the council should use some measures to tackle this." (P10)

Despite the reservations made by some of the contributors about the use of geolocation data, most groups have settled on the idea of visualising energy-related information at a lower spatial resolution than the building level such as block[4] level. Finally, although the attendees had different preferences with regards using 2D or 3D maps, they agreed that the user should be given the option for both as discussed in the below statement,

"…If you go to a train or bus station, you can only find 2D, but we decided to use the 2D and 3D because some people might be comfortable with the 2D and some other might find it easier to use the 3D." (P3)

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[4] According to [68], a block is group of buildings bounded by four streets.

4.3.5. Community-related features and suggestions

Despite some data sharing and comparison concerns, the majority of the groups welcomed the idea of creating a sense of competition between the community members to encourage home-energy saving. In line with the survey results, 13 contributors found ranking and colour coding beneficial. In this respect, participant (P17) advised, *"Ranking can be done here on the map, you can, for example, use different colours"*.

While the majority of respondents recognised the importance of reward, they suggested that it should be only symbolic (non-monetary or intrinsic) to maintain a long-term engagement. This is in good agreement with many studies in the literature suggesting that monetary incentives are not necessarily superior to the non-monetary ones and could deteriorate morals [60]. One of the suggested forms of non-monetary rewards was to allow users to collect rewards points based on certain actions. Furthermore, awarding a "Green *household certificate*" when they have reached a certain number of points. Other suggestions included the announcement of the winner of the month in the newsfeed.

Although the attendees were motivated about reducing their carbon footprint in various ways (e.g. self-evaluation and social comparisons), the authors felt that community interaction related features have not been the central focus in their design suggestions. More precisely, the contributors focused more on the visualisation of their energy-related information than on the design of community based-features. Indeed, the majority of their community-related suggestions revolved around community messaging boards and newsfeed with no consideration of features around action sharing and community goal setting. For example, participant P13 mentioned,

"… Now, if you want to chat with any one of them to share information or to communicate on how you can save more energy, the user could click on a building with a green colour and have a chat with that person." (P13)

Part of this issue could be associated with the present forms of social media dominating the participants' perception of community interaction. Another contributing factor is the dominance of in-home smart meter displays, which solely focus on visualising the energy consumption of a given household. However, since there is not enough scientific evidence to reinforce the above hypothesises, more research is needed in that respect.

4.3.6. Integration with other applications

In response to the busyness of the households and the impact on engagement in energy-saving activities, 10 participants (P11-P18, PA and RI) recommended developing a multi-purpose Eco-feedback app by integrating features from third-party applications and websites. In this respect, participant P15 mentioned, "*The other part that I am trying to convey in this app is not to use many apps but to use the only one which can serve for multi-purposes".* (P15)

The groups' suggestions revolved around linking the developed app with the energy suppliers' ones to pay their energy bills and/or to check their energy usage. Furthermore, they focused on hosting some features from websites that compare and suggest various energy tariffs such as U-Switch. Again, the advantages of multi-purpose applications over the single-purpose ones is a well-documented area of research [61], which widely acknowledges that multi-purpose applications are customisable offering a high degree of simplicity. Furthermore, they are ideal for solving multiple problems efficiently and cost-effectively. For those reasons, there will be a consideration for integrating third-party applications in the developed community-based Eco-feedback tool.

5. Implication on the design of community-based Eco-feedback interface (Phase 4)

Tables 5, 6, and 7 represent the summary of our research findings. Moreover, highlight their implications on the final design of the community-based Eco-feedback interface, which is addressed in more details in the subsequent sub-sections.

5.1. General layout and organisation

Figures 21 depicts the developed community-based eco-feedback interface on the initial launch, whereas figure 22 illustrates the full interface with panels 3 and 4 expended. As suggested by most of the community members, the layout of the community-based Eco-feedback interface will be composed of 4 panels. However, in response to suggestions from the community (see section 4.3.2), only panels 1 and 2 appear on the initial application launch (see figure 21). This means that the users need to expand panels 3 and 4 to obtain more information on disaggregated energy usage, energy saving suggestions, and consumption in the area.
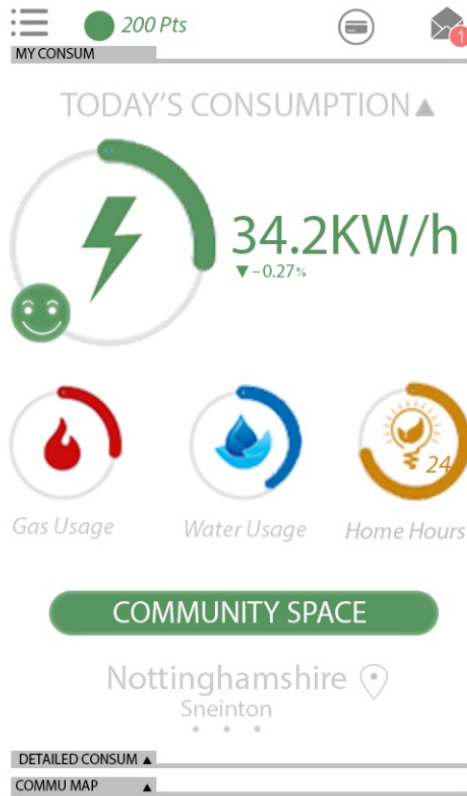
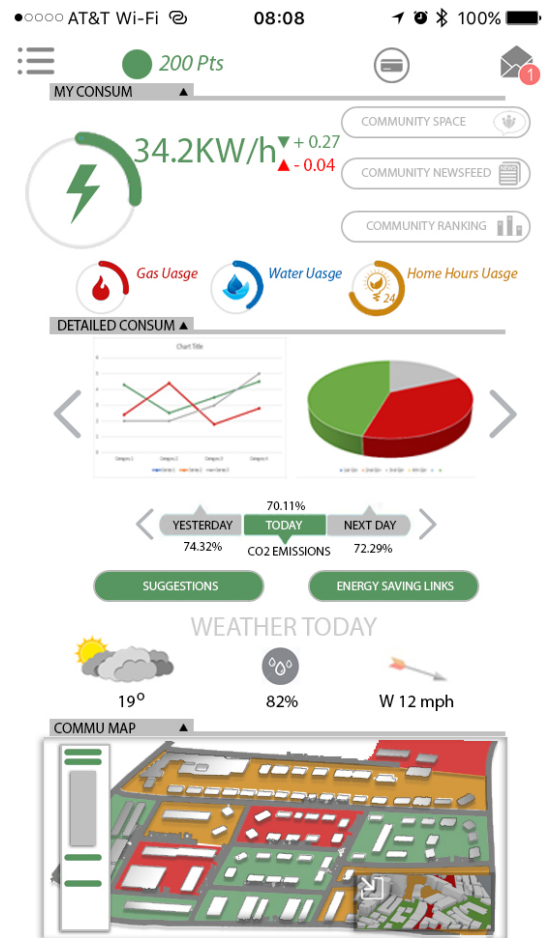**Figure 21.** Community-based user-interface on the initial launch

Figure 22. The full version of Community-based user-interface with panels 3 and 4 expanded.

In both the initial and full versions, panel 1 comprises features such as menu and settings in addition to my current consumption status, reward points, and notifications. Conversely, panel 2, in turn, consists of two areas (figure 21). The first one provides users with aggregate information about their energy usage and compares it to the average consumption in the area (e.g. +10%/ smiley emoticons). The second area; however, encompasses a community space which was particularly designed to promote community interactions and engagement in energy-saving activities. In particular, users can share their energy-saving actions and know about the ones of community members who, in turn, are ranked based on their energy consumption (see figure 23). To get suggestions and/ or find out more about the saving measures of others, it is possible to start a discussion with them in the community interaction space located below the community ranking/saving area (figure 23). The community space is also equipped with a newsfeed widget located at the top, which offers community members regular updates on different energy saving matters.

Panel 3, which only appears in the full version, offers users the possibility to consult their disaggregated energy consumption related information such as energy graphs, weather widget, and carbon footprint. In addition to that, it provides them with suggestions and links to energy savings including energy-saving support schemes. Finally, panel 4 of the expended version is equipped with a 2D and 3D maps visualising the energy consumption of the area (see figure 22).

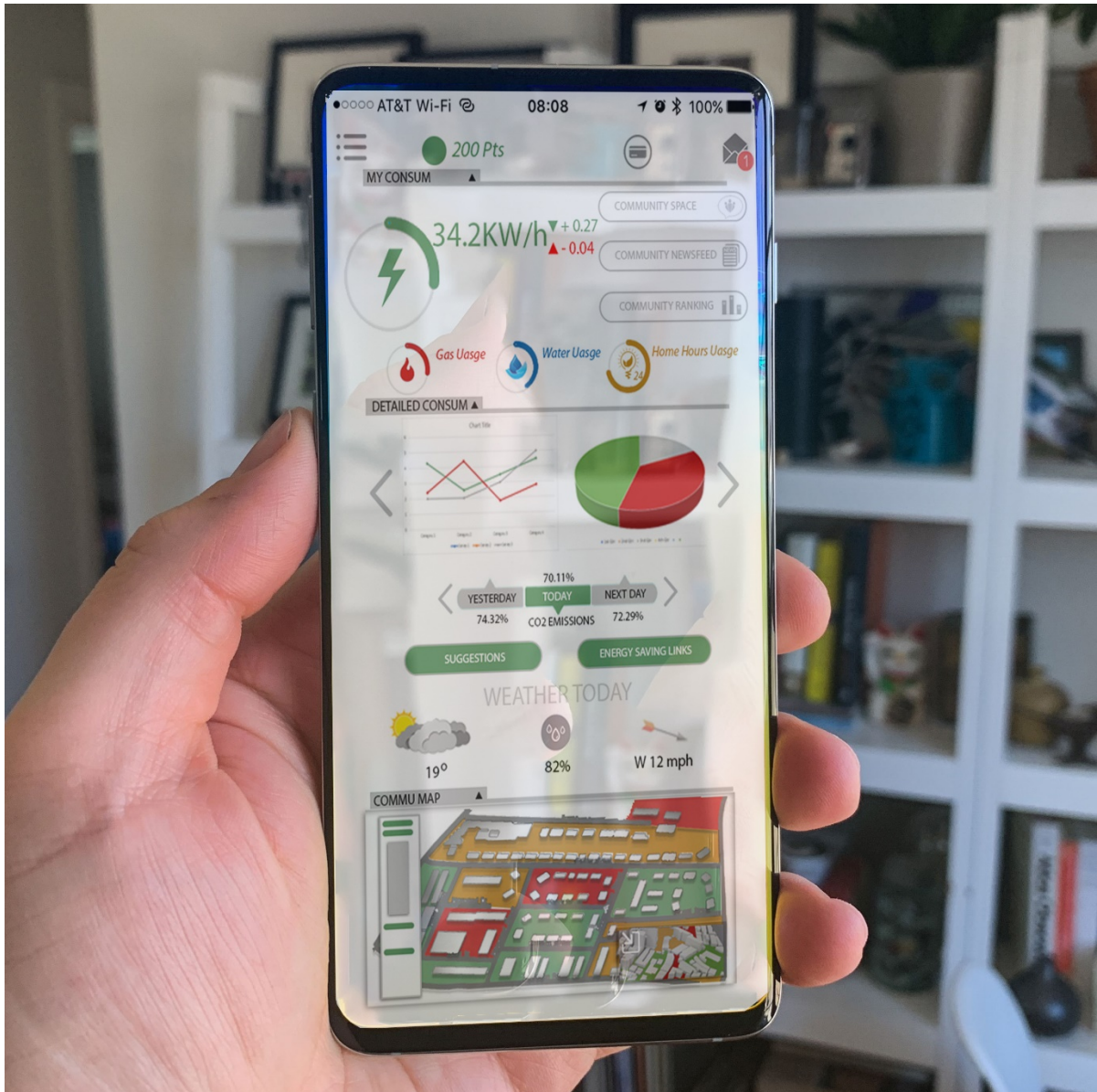**Figure 23.** The Community space of the developed eco-feedback interface

Figure 24. The full community-based eco-feedback application visualised on a smartphone

5.2. All other features

Tables 6 and 7 (below) summarise the non-layout suggestions regarding the community-based Eco-feedback interface. Moreover, they outline the list of actions that have been taken to finalise its development.

First, the mapping of energy consumption related data onto the 2D/3D maps in panel 4 is performed at a rough spatial resolution (Block level) instead of the building level. This is mainly to protect the participants' privacy while reducing intrusiveness, which helps community members concentrate

solely on energy-saving activities. Similarly, to address the feeling of guilt or being under pressure as a result of consuming high energy figures than others, all users will bear a pseudo name when interacting and/ or sharing data with other community members. Furthermore, they possess the full control of their social network where users can invite/ add members and determine the type of information to be shared/ known.

Since they were widely accepted by the community members (see 4.3.5), competition-related features (e.g. ranking) and non-monetary reward mechanisms such as green certificate and winner of the month, have been implemented in the developed interface. The green certificate is awarded upon reaching certain rewards points. These, in turn, are earned based on performing specific actions such as reporting energy-saving activities, accessing the suggestions, interacting with the community, and meeting saving goals. Members with a green certificate are identified by small medal next to their pseudo name (figure 23). Apart from that, at the end of each month, there will be an announcement of the winner of the month for consuming the lowest energy figure in the area.

Finally, in response to proposals to develop a multi-purpose application as discussed in 4.3.6, a payment feature has been integrated where users can directly pay their utility bills (figure 11). However, other features from third party websites and apps such as tariff comparison have not been considered in this release. This is because switching to cheaper tariffs is sometimes associated with an increase in energy usage [62], which contradicts the purpose of the developed community-based eco-feedback app. Nevertheless, more research is needed to help identify methods for incorporating such a feature while maintaining good engagement levels in energy-saving activities.

Table 5. Summary of research findings and their implications on the final design of the interface (Part 1): **Note:** ** elements the emerged in the focus groups' discussions and were not included in the survey

	Design brief specifications based on the survey findings		Focus groups findings		Implications on the final interface design
	Elements addressed in the survey	**Focus design brief specifications**	**Areas covered by the focus groups' participants**	**Main interface suggestions**	**General Layout and organisation**
Survey / **Focus Groups**	**Version of the Eco-feedback interface**	• 51.10% smartphone version • 25.5% web version • 12.6% pc/laptop version • 9.1% social media plugin • **Researchers recommendation(s):** focus on developing a smartphone version for now.	**Interface layout and customisability** *	• 15 out of 20 suggested a portrait orientation ** • 2 out of 3 interface designs had 4 panels ** • Despite minor variations, Panel 1 was allocated to the menu, notification, interface preferences and user profile ** • Panel 2 of two interfaces was dedicated to showing aggregate energy usage and its cost ** • Panel 3 of all interface designs included disaggregated energy consumption (historical and current). However, the designers of two interfaces wanted to know their predicted energy usage * • Panel 4 of two interfaces was allocated to visualising the energy performance of the neighbourhood on 2D/3D maps **	• The final interface has 4 panels. • Upon launching the app, only panels 1 and 2 appear. • Users can expand panels 3 and 4 to obtain further information. • **Panel 1** contains menu, settings, notifications, my current consumption status, and reward points. • **Panel 2** comprises two parts. The first part provides users with aggregate information about their energy usage with a comparison in relation to the average user in the area. • The second part of **panel 2** encompasses a community space where users can know/share energy actions, interact with other users, see their ranking. The community space also contains a newsfeed widget. • **Panel 3** offers users the possibility to consult their disaggregated energy consumption related information such as energy graphs, weather widget, and carbon footprint. • **Panel 3** also provides users with eco-suggestions including external links (e.g. Energy saving support schemes)
	Type of fuel to share and receive information about	• Electricity (42% of answers) • Gas (36% of answers) • Other fuel sources (22% of answers). This was mainly about hot water consumption **Researchers recommendation(s):** • Users should be given an option to customise fuel related information.			
	Type of information to be known/shared	• Quantity of energy usage (17% of the responses) • Cost of used energy (19% of the answers) • Information about home appliances and heating system (30.4% of the answers) • Information about home energy rating (15.9% of the answers) • Action made to save energy (16.1%) **Researchers recommendation(s):** • Users should be in full control of the type of information to be share/known. • Some users wanted to know their off-peak energy tariff and real-time energy feedback.	**Interface complexity ** and level of information detail.**	• 90% of the participants suggested that the interface should be easy and simple to allow them to rapidly access different information **. • The initial launch of the interface should be very simple **. • 8 participants advised that users need to be in full control of the of the interface complexity **. • Level of disaggregation should be customisable based on users saving goals and preferences.	

Table 6. Summary of research findings and their implications on the final design of the interface (Part 2). **Note:** ** elements the emerged in the focus groups' discussions and were not included in the survey

Survey

Design brief specifications based on the survey findings	
Elements addressed in the survey	**Focus design brief specifications**
Data sharing with community members	• 53% preferred to know and share data with others. • 9.3% did not want to know and share data with others. **Researchers recommendation(s):** • Users should have the option to choose if they want to know and/ or share data with others. • Comparison measures such as comparison with the average energy household, should be included.
Eco-suggestions/tips	• 65% wanted to receive eco suggestions/tip. • 29.8% wanted to receive eco-suggestions/tip but if they do not affect their comfort. **Researchers recommendation(s):** Eco-feedback interface should provide users with eco-suggestions.
Eco-suggestions/tips from external sources (e.g. videos and blogs)	• 49% believed that it is very / extremely important to receive suggestions from external sources • 24.5% believed that suggestions from external sources are not important. **Researchers recommendation(s):** • External suggestions should be included in the interface.

Focus Groups

Focus groups findings		Implications on the final interface design
Areas covered by the focus groups' participants	**Main interface suggestions**	**General Layout and organisation (continued)**
Data sharing and privacy	• 3 out of 20 participants expressed privacy concerns about sharing data with community members. • Some of them highlighted the risk of others wondering why certain community members consume more or less **. • 4 out of 20 participants believed that sharing data with others put some social pressure on them which can cause them stress and anxiety **.	• Panel 4 comprises 2D/3D maps visualising the energy consumption of the area. **All other features** • Energy consumption data will be visualised on 2D/3D maps of the area but with a rough spatial resolution (block level) instead of the building level. • Some of the focus groups participants suggested that high energy consumers in the area could feel stressed and anxious as a result of social pressure. This was addressed by allocating nick names to community users when interacting with each other or when their energy usage will be shared. Moreover, their personal information will be kept secret. • Possibility to invite/ add friends in the community space in panel 2. This invitation is accompanied by a list of information that the user permits to share and know with the invitation sender.
Relevance and type of geographical data visualisation **	• More than 50% of participants found that geo-locating energy consumption data is the main source of privacy concerns **. • 5 Participants found maps unnecessary and suggested comparing their energy usage against their social network who can be added to the interface **. • 8 participants believed that geolocated energy data is indispensable to monitor and promote pro-environmental behaviour **. • 70% of the participants suggested that data should be visualised at lower spatial resolution than the building level (Block level) **. • Users should be given the option to choose between 2D/3D maps **.	

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Table 7. Summary of research findings and their implications on the final design of the interface (Part 2). Note: ** elements the emerged in the focus groups' discussions and were not included in the survey

Design brief specifications based on the survey findings		Focus groups findings		Implications on the final interface design
Elements addressed in the survey	Focus design brief specifications	Areas covered by the focus groups' participants	Main interface suggestions	All other features (continued)
Focus Groups				
		Community related features and suggestions	• Most community suggestions revolved around community messaging boards and newsfeed**. • 13 participants recognised the importance of ranking in promoting engagement in pro-environmental behaviour. • The majority believed that reward is important but should be symbolic to maintain a long-term engagement**. • Participants suggested that users should collect reward points based on performing energy saving actions. Upon reaching a score threshold, users should be rewarded with a "Green certificate"**. • The most efficient user in the area should be announced as the winner of the month in the newsfeed section**.	• As suggested by the focus groups' participants, a non-monetary award in the form of a green certificate has been added to the interface. This should be announced in the newsfeed and user will be notified. Moreover, users with a green certificate should have a small medal next to their profile icon. • Lowest energy user of the month will be announced in as the winner of the month in the newsfeed section. • In response to suggestions about developing a multi-purpose application, a bill payment feature has been integrated in **panel 1.** • Tariff comparison features will not be integrated in this release. This is because some studies have shown that [62] switching to cheaper tariff might lead to an increased energy usage. • Users will be notified about off-peak tariff in panel 1
		Integration with other applications**	• 10 Participants recommended that the developed Eco-feedback interface should be multi-purpose by integrating third party applications and websites**. • Allowing users to pay their bills through the developed Eco-feedback interface**. • Hosting service such as U-Switch to allow users compare different tariffs**.	
Survey				
Ranking based on energy consumption	• Ranking would help promote domestic pro-environmental behaviour (45% of respondents) • Ranking would help promote domestic pro-environmental behaviour but only when there is a reward (35.80% of respondents) • Ranking would not help promote pro-environmental behaviour (13.2% of respondents) **Researchers recommendation(s):** • The ones aged 25-34 are more likely to gravitate towards reward.			

6. Conclusions and Future Work

Our analysis of existing community-based Eco-feedback applications found that there is a lack of co-design (participatory) initiatives during their design stage. Indeed, much of the current conversations on community engagement in the development of Eco-feedback systems is limited to testing eco-feedback systems and providing suggestions during the implementation stages to assist their improvement.

To address the research gap and explore the potential of community engagement in the design process of eco-feedback applications, this research aimed to utilise a participatory (co-design) approach to design an accessible community based eco-feedback interface in collaboration with Nottingham city community members and energy experts. First, we conducted an online survey questionnaire with 151 participants with distinct socio-economic characteristics and environmental knowledge to determine their preferences about the various aspects of the developed eco-feedback interface. These aspects comprised: familiarity with ICT, technology preferences, privacy, social interaction, and type of feedback. Secondly, the survey findings have been used to develop a design brief containing the eco-feedback interface specifications. The design brief was used by 20 participants including the authors, energy experts, and community members living in Nottingham to collaboratively develop interface prototypes through two participatory focus groups. Finally, premised on the interface prototypes and suggestions/ preferences that emerged during the focus groups, the researchers produced a consensual version of the community based eco-feedback interface.

Although generalisations are limited and cautious due to the demographics of the sample, the analysis of the survey findings permitted to gain insights into themes (e.g. privacy) whose influence on the engagement in pro-environmental behaviour is still debated in the literature. As depicted in tables 5, 6, and 7, the analysis of the survey questionnaire advised that respondents, regardless of their socio-economic profile, attributed the lack of engagement in home energy-saving activities to the paucity of information and busyness to a lesser extent. Furthermore, they recognised the importance of developing eco-feedback applications that contain social interaction features such as ranking in promoting pro-environmental behaviour. As for their preferences, most respondents preferred a smartphone version and sought eco-suggestions/ tips including the ones from external sources such as videos and websites. They also suggested obtaining information about their electricity, gas, and/ or hot water consumption and found both aggregate and disaggregate information equally important. Moreover, the majority showed no reservation about sharing their information anonymously with

other community members. However, to allow for a transparent and democratic participation process, users should be in full control of the types of information to be shared/ known and its level of disaggregation.

While the participatory focus groups permitted the development of three interface design proposals, the adoption of this participatory (co-design) approach was invaluable to this research. First, the interaction between different participants during the focus groups permitted the generation of new ideas and insights that were not included in the survey questionnaire and could push the use of eco-feedback applications "beyond providing feedback". Examples of the themes that emerged are 1-interface complexity, 2-integration of third-party applications (e.g. bills -payment and integration of tariff comparison websites such as U-Switch), 3-community related features including reward points, green certificate, and winner of the month. Second, the participants have not only demonstrated a high level of awareness to potential ethical issues that could arise from community interactions (e.g. social pressure) but also came up with practical solutions which align with the findings of [63]. Mapping energy-related data at the block level instead of the building level is an example of the suggested solutions.

In response to the survey and focus groups findings, the final interface was designed in a way that offers some degree of flexibility, customisation, and simplicity to the users depending on their preferences. In this respect, the interface starts with only two panels containing minimal information on their aggregate electricity, gas, and/or water current usage with an indication of users' performance in relation to the average usage of the area. To gain deeper levels of information (e.g. disaggregate energy usage or predicted energy consumption), interact with the community, and/ or consult the energy performance of the neighbourhood, users need to expand panels 3 and/or 4 (figure 21-24). To address privacy concerns and social pressure expressed by the participants, users were given control over what type of information to be known/shared with other community members.

Despite the time and efforts dedicated to the development of this community-based eco-feedback interface, there is more to be done. This is because some of the aspects require further improvement whilst others, need to be studied in more depth. Firstly, although the community were able to develop the interface layout and main features, the time constraints of this study prevented them from investigating the design of individual entities such as visualisation of feedback. While there is a wide range of visualisation techniques to aid informed decision-making, research has shown that the use of inappropriate eco-visualisation techniques could lower the engagement levels in energy-saving

activities [64,65]. Therefore, studying the effectiveness of different visualisation techniques is among our future research priorities. Another area that requires attention in the near future is the study of the relationship between users' level of motivation for energy-saving and their preferences towards the level of disaggregation. This will in turn help establish energy profiles that govern the level of disaggregation and the complexity of meeting energy-saving goals depending on the user motivations and experience with home energy saving. Finally, upon the completion of the planned research, the interface has, in turn, to be implemented and tested in a residential setting to help improve its performance and evaluate some features. In particular, this will enable the assessment of the impact of third-party applications such as tariff comparison on the level of community engagement in energy-saving activities. Initial signs are positive though that these collaborative community initiatives have the potential to address some of the challenges inherent in feedback and increase the acceptance, adoption and impact of behaviour change led solutions.

Acknowledgement

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Appendix A

Section 1: Environmental Knowledge

1. How is your knowledge about home energy saving?

○ Not knowledgeable about

○ Somewhat knowledgeable about

○ Knowledgeable about

○ Very knowledgeable about

2. Do you feel responsible for reducing your home energy consumption?

○ Yes

○ No

○ Not sure

○ Other

3. Based on your experience, why people don't engage in pro-environmental behaviour such as reducing their home energy consumption? (*Check all that apply*)

☐ Ineffective tools of communication

☐ Lack of information about energy saving

☐ No real benefit for individuals

☐ Time and availability

☐ Not worried about their bills

☐ Other

4. What actions have you made recently to save energy?

Type your answer here

Section 2: Preferences about the developed Eco-Feedback interface

4. How comfortable are you with technology such as computers and smartphones?

○ Very comfortable

○ Somewhat comfortable

○ Somewhat not comfortable

○ Not quite comfortable

○ Other

5. How important do you think is to develop applications and devices that assist with energy savings?

◉ Not important

○ Less important

○ Somewhat important

○ Very important

○ Extremely important

○ Other

6. We are developing a software application o help the community reduce their home energy consumption. What would be your preferred software version? (*Check all that apply*)

☐ Website version

☐ Integrated into Social media such as Facebook and Twitter

☐ Smartphone application

☐ PC/Laptop application

☐ Other

7. What are your thoughts about sharing energy consumption data **anonymously** with the community members? (please note that your personal information will NOT be shared)

○ I prefer to share only

○ I prefer to know only

○ I prefer to share and know

○ Neither

○ Other

8. The software that we are developing can give you suggestions on home energy saving. Would you consider those suggestions to save your home energy consumption?

○ Yes, I would

○ Yes, but as long as the suggestions do not affect my comfort

○ No

○ Not sure

○ Other

9. Please rank the importance of the below feature from **least (1)** to **most (5)** important.

	1	2	3	4	5
Receiving suggestions to help you save energy from external sources in forms such as videos and blogs?	☐	☐	☐	☐	☐

10. What type of fuel would like to receive or share information on? (*Check all that apply*)

☑ Gas

☐ Electricity

☐ Other

11. What types of information that you are willing to share/know? (Check all that apply)

☐ Cost of your energy usage

☐ Quantity of your energy usage in kWh (meter readings)

☐ Information about your heating system (e.g. Type of boiler)

☐ Information about your main home appliances (e.g. Fridge and Cooker)

☐ Your home energy rating (e.g. A+, C, D, etc...)

☐ Actions made to save energy consumption (e.g. changing old light bulbs to LED)

☐ Other

12. Do you think **ranking** households based on their energy consumption (from the lowest to the highest) would help them engage in reducing their home energy consumption?

○ Yes, it definitely would.

○ No

○ Yes, but only if there is a reward

○ No, even if there is a reward

○ Other

Section 3: Personal information

13. What is your gender?

○ Male

○ Female

14. Which of the following categories best describe your age?

○   Under 21

○   21-24

○   25-34

○   35-44

○   45-54

○   55-64

○   65 Or Older

15. What is your occupation?

○   Student

○   Employee

○   Self-employed

○   Retired

○   Other

16. What is your level of education?

○   Secondary/High School

○   College

○   Bachelor

○   Masters/PhD

○   Other

17. Please, you can use this comment box for any comments or suggestions you would like to add?

Type your answer here

Appendix B

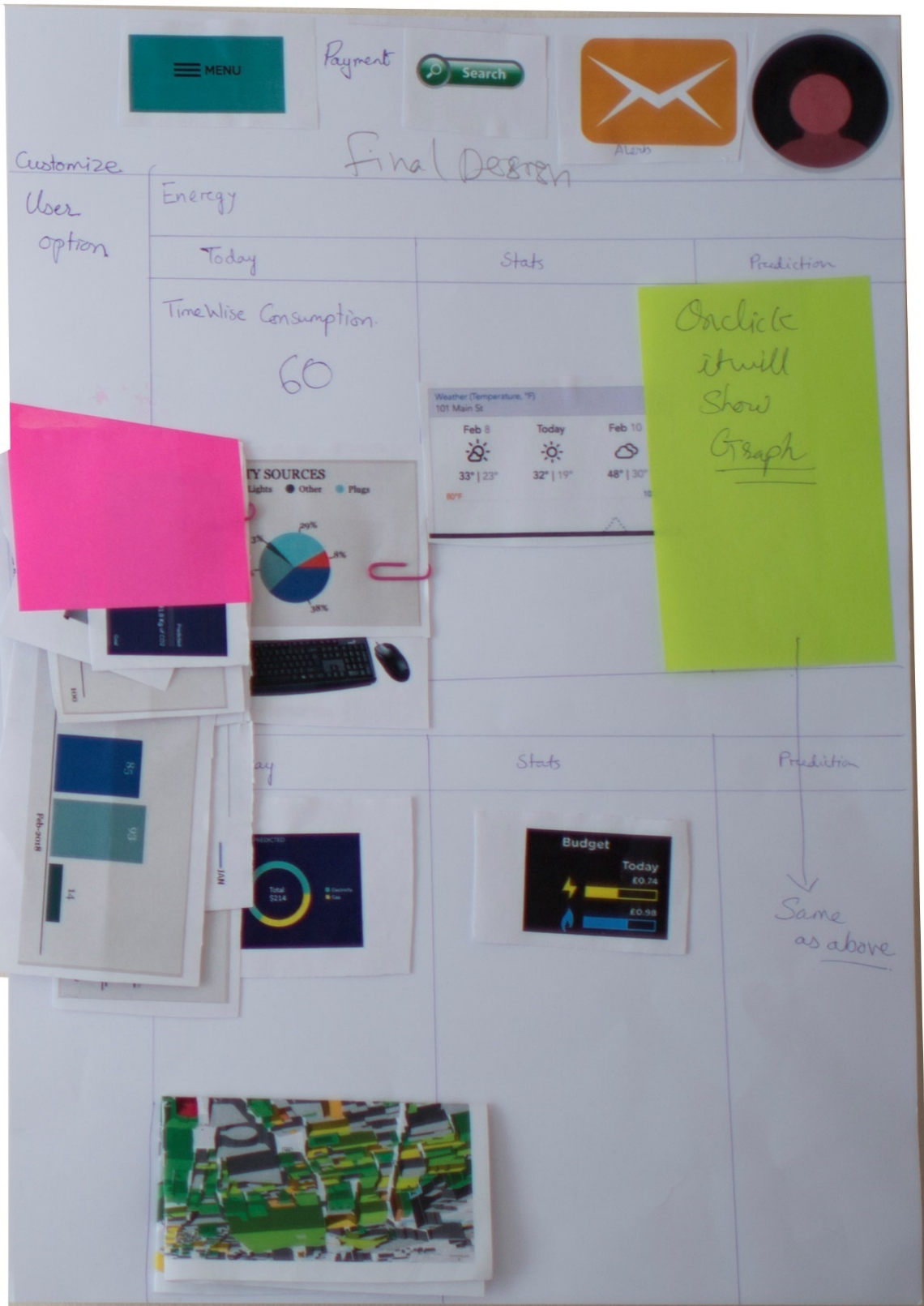Figure 4.close-up image of interface proposal 1

Figure 5. Close-up image of interface proposal 2

Figure 6. Close-up image of proposal 3