Energy Informatics

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Interface design for residential energy feedback, in the Indian context

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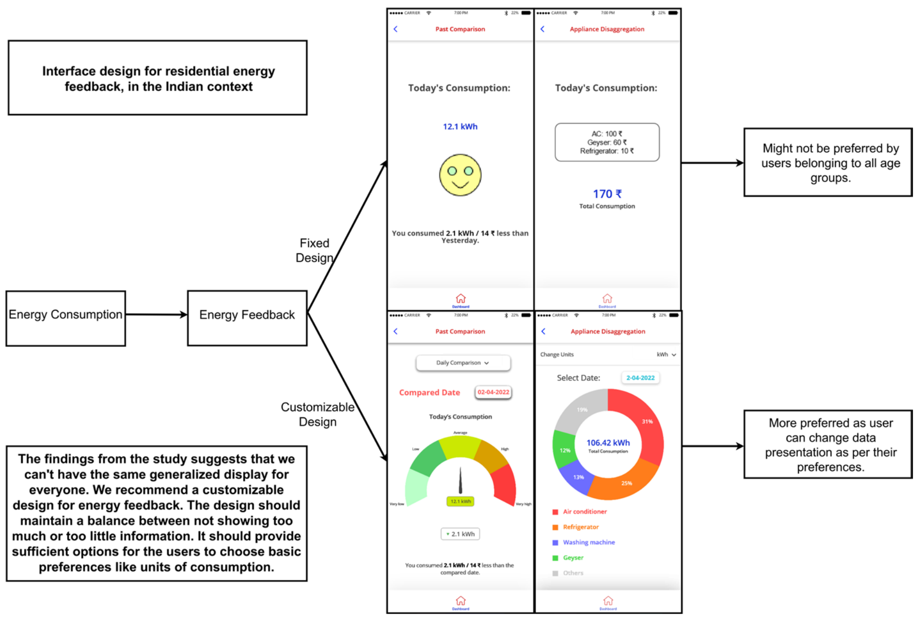
Abstract

Global access to electricity has increased from 78.2% to 2000 to 90.5% in 2020, resulting in an increased electricity demand worldwide. Unlike commercial electricity consumption, which is managed by professionals, residential consumption is managed by the householders, who often lack insight into their energy usage. Quality feedback, including detailed energy consumption and tips, can lead to substantial household savings. There are several mediums for providing energy feedback, such as Short Message Service (SMS), postal letter, email, mobile app, and In-Home Display (IHD). Studies suggest that feedback through electronic media can save up to 20% of energy consumption. In this work, we aim to design mobile application interfaces that can maximize energy savings through effective feedback. The level of savings realized is dependent on the user's preferences and understanding of the information presented. User preferences are subjective of their profile (e.g., age, occupation, income) and the cultural context (e.g., country). The possibility of energy reduction is high when the provided information matches the user preferred information for feedback. Smart homes have recently been included as an annexure in India's building energy code (Eco Niwas Samhita 2021), indicating a growing demand for quality energy feedback in India. However, there is a lack of research that addresses what feedback information is suitable for Indian users. We conducted two questionnaire-based surveys, one to understand users' preferences for feedback information and another to validate the designed mobile application interface screens. The surveys were conducted on two age groups, young and middle-aged adults. A Chi-Square Test of Independence was performed to assess the relationship between the user's preference for feedback information and their age group. Participants identified total energy consumption, appliance level disaggregated information, energy-saving tips, goals, and historical consumption comparisons as the top five information types. In contrast, normative comparison was the least preferred information. The follow-up design validations suggest that the interface should be customizable to accommodate the varying preferences of users. The current findings will help customize the energy feedback display UI design as per the Indian population.

Keywords: Energy-feedback, Residential, Interface-design, User centric feedback, In-home-display

Graphical Abstract



Introduction

In India, the percentage of households with access to electricity has increased from 55% to 2001 to more than 80% in 2017 and the residential energy consumption has almost tripled since 2000 (Bhardwaj Ankit 2017). The increase in the consumption is also due to population increase, economic growth, and advancements in new technologies (e.g., smartphones and televisions) (Ehrhardt-martinez and Donnelly 2010). Changing building materials and components (e.g., double-glazed windows), replacing old appliances with more efficient ones, and promoting a change in the behaviour of users can help reduce residential energy consumption. Behaviour has been one of the most studied areas in Psychology (Daae and Zachrisson 2014; Jackson et al. 2004; Ajzen 1991; Klöckner and Blöbaum 2010). Increasing awareness about energy consumption can be a powerful tool in promoting behavioural change (Yun et al. 2015; Sopha 2013). However, users' lack of knowledge about their own household energy consumption often presents a significant barrier to changing their behaviour and reducing their energy usage (Fischer 2008).

Raising awareness about energy consumption is crucial for promoting energy conservation (Darby 2001; Suppers and Apperley 2014; (Vassileva et al. 2013). One way of achieving this is by presenting information on energy use through electricity bills (Chiang et al. 2012). However, providing this information alone is insufficient to drive energy savings. To achieve meaningful reductions in energy consumption, it is necessary to provide energy feedback that is easy to understand, presented in near-real time, and includes specific details that enable users to take action (Darby 2006; Abrahamse et al. 2005). Electronic media, such as in-home displays (IHDs) and mobile applications, can provide personalized energy feedback to users, leading to up to 20%

energy savings (Chiang 2015; Abrahamse et al. 2005). While several studies have quantified the impact of energy feedback on energy consumption, few have focused on the design of feedback interfaces for residential users. The lack of guidelines for designing effective residential energy feedback interfaces has motivated this study.

Previous research has established that a variety of factors, such as the location, orientation, and size of the home, household composition, members' activities and schedules, awareness of energy conservation, and income levels, can influence residential energy consumption (Blasco Lucas et al. 2001). While factors such as location, orientation, and income are relatively constant and user-dependent, designing effective residential energy feedback interfaces requires considering other factors, such as users' preferences and comprehension of feedback information, which can vary based on demographic and cultural contexts (Fischer 2008; Moura et al. 2019; Bonino et al. 2012; Ehrhardt-martinez and Donnelly 2010; Yun et al. 2015; Vassileva et al. 2012; Chiang et al. 2012; Canfield et al. 2017). For instance, a study on user preferences and understanding of energy feedback found that consumers often lack a clear understanding of their energy consumption and need more detailed information, particularly about the proportional consumption of individual appliances, to make informed choices about energy use (Karjalainen 2011). Another study designed an in-home display interface for the Brazilian context. Using a questionnaire-based survey, they aimed to better understand user preferences and comprehension of feedback information. Based on their findings, they developed interface prototypes for three distinct age groups: children, young adults, and older adults. (Moura et al. 2019).

In the current state of research on energy feedback interfaces, several gaps have been identified, including a lack of respect for user privacy, short study duration, insufficient comparisons between similar households, absence of personalized feedback, and small sample sizes (Dane et al. 2020). Our study aims to find what are the aspects that users in India would prefer through survey based approach while (1) obtaining user consent and ensuring that no personal information is made public, with the approval of the institutional ethics committee; (2) conducting the survey with a reasonably large sample size of 446 participants; (3) performing inferential statistical tests, such as the Chi-Square Test of Independence, to determine the statistical significance of our results, in contrast to the descriptive analysis provided in most previous research; (4) focusing on the design of residential energy feedback interfaces; and (5) validating our final interface design with users.

The methodology of this study involved a questionnaire-based survey to gather user preferences and understanding about energy feedback in the Indian context. The survey was conducted on two age groups, and customized screens were designed based on their preferences. The final interface designs were validated with users from the same focus groups using another questionnaire-based survey.

Energy feedback

Energy feedback can help make energy consumption more visible and turn energy consumers from a passive to an active state (Serrenho et al. 2015). It involves providing users with information about their energy consumption, which can help raise awareness about energy conservation and promote sustainable behaviours (Froehlich et al. 2010). However, many users lack understanding about their household energy consumption (Burgess and Nye 2008), making feedback an important tool for increasing awareness and promoting more sustainable energy practices.

Research has shown that the type of feedback plays a significant role in the amount of energy savings achieved through energy feedback (Darby 2006). Builds a taxonomy for energy feedback based on different characteristics of feedback such as frequency, type, presentation style, and methods of access (Agarwal et al. 2023). Feedback can be classified into three types: direct feedback which is available on demand (displays, trigger devices, prepayment meters, cost plugs on appliances), indirect feedback where raw data is processed by the utility and sent to the customer (frequent bills) and inadvertent feedback (solar water heaters and photovoltaics) (Darby 2001). The classification is based on parameters such as frequency (delayed or immediate feedback), medium (e.g., paper-based bills, in-home displays), and the type of information (e.g., historic, or disaggregated consumption) (Darby 2001, 2006). In the following sections, we discuss these parameters in more detail.

Feedback frequency

Feedback frequency refers to how often users receive feedback information, such as yearly, monthly, or daily. Studies indicate that feedback should be provided frequently and not exceed monthly or annual consumption as this can lead to incorrect estimates and cause users to abandon the device ((Darby 2006, 2010; Fischer 2008; Anderson and White 2009; Ueno et al. 2006). Generally, the more frequently feedback is given, the more significant its contribution to changing user behaviour (Fischer 2008; Roberts and Baker 2003). It is also important to allow users to choose the frequency at which they receive feedback on their device (Darby 2010).

Additionally, feedback resolution is a critical aspect of feedback frequency, indicating the period for which a user wants the data to be updated on the feedback medium. Feedback resolution options include daily, weekly, monthly, or near real-time updates. For example, a user might want to receive a monthly bill for their energy consumption (monthly feedback frequency) and in that, weekly or daily consumption split is the feedback resolution.

Feedback medium

There are various ways to provide energy feedback to users, such as In-Home Displays (IHDs), SMS, postal letters, email, mobile apps, and mixed modes (Zangheri et al. 2019). These feedback methods can be broadly classified into two types: electronic media and written material (Froehlich et al. 2010; Fischer 2008; Froehlich 2009; Schleich et al. 2013; Kerr and Tondro 2012). The effectiveness of energy feedback heavily relies on how the information is delivered to the user. Research suggests that electronic media is more efficient than written material in reducing energy consumption (Darby 2010; Fischer 2008; Abrahamse et al. 2005; Faruqui et al. 2010; Wood and Newborough 2003). Therefore, it is crucial to choose the right feedback medium to ensure maximum energy savings.

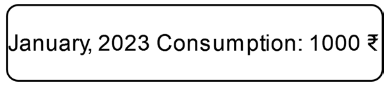


Fig. 1 Total consumption

Fig. 2 Disaggregated consumption

Type of information

Information is the key element of energy feedback. It is something that is finally going to reach the energy consumer. Due to the diversity in the feedback content, breakdown of information and it's mode of presentation, it becomes challenging to determine the relevant information that can effectively alter user behaviour towards energy consumption (Fischer 2008). Therefore, it is not necessary for a device to present all available information on energy consumption to the user (Anderson and White 2009), (Faruqui et al. 2010). Instead, it is crucial to investigate the specific types of information that should be presented to users, enabling them to learn from their consumption habits and reduce their energy consumption. Generally, the information can be classified into the following types:

- Total consumption

Total consumption refers to the quantity of energy used by a household over a specific period of time. This is the most basic information provided in energy feedback. When it comes to electricity bills, the total consumption is typically presented in both energy and monetary units. An example of the total energy consumption for a month in Indian rupees (₹) is displayed in Fig. 1.

- Disaggregated consumption

Disaggregated consumption refers to the breakdown of energy usage at the appliance or room level. This type of information is extremely valuable for understanding which devices or areas of the house are consuming the most energy (Fischer 2008; Karjalainen 2011; Wilhite and Ling 1995). Disaggregation is sometimes referred to as "data granularity," as discussed in reviews by Froehlich (2009) and Kerr and Tondro (2012). By providing detailed information about energy usage, disaggregation can help motivate users to conserve energy by using devices less frequently or by replacing them with more efficient models (Fischer 2008). Figure 2 provides examples of disaggregated energy consumption at both the appliance and room level, presented in Indian rupees (₹).

- Historic and normative comparison

Efficient behaviour change can be achieved by comparing consumption data, which reveals whether a household's current usage is above or below average consumption (Wilson et al. 2013). Such comparisons can be either historical (comparing current usage

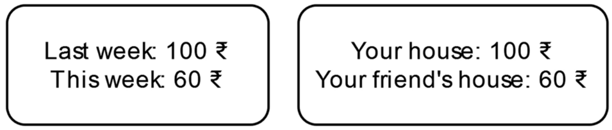


Fig. 3 Historic and normative comparison

with past consumption in the same household) or normative (comparing with other households). Even households that already use energy efficiently can be motivated to reduce their consumption through historical comparisons (Chiang et al. 2014). Normative comparisons, on the other hand, can leverage factors such as competition, social comparison, and ambition to encourage reductions in energy use (Fischer 2008; Abrahamse et al. 2005). However, for normative comparisons to be effective, the compared households must have similar characteristics, such as size, location, orientation, type of users, and type and number of appliances (Karjalainen 2011; Iyer et al. 2006). Figure 3 provides an example of both historical and normative energy consumption comparisons, presented in Indian rupees (₹).

- Goals and targets

The consumption target refers to a threshold value that can be reached in terms of energy consumption (Roberts and Baker 2003; McCalley and Midden 2002; Suppers and Apperley 2014; Karjalainen 2011; Sundramoorthy et al. 2011). Including projected consumption in the goals and targets can help users understand how much energy they may consume the following day or by the end of the month. It's important to carefully set consumption goals, ensuring they are neither impossible to achieve nor too easy, which can discourage users and lead to device abandonment (Krishnamurti et al. 2013; Wood and Newborough 2003). Figure 4 provides an example of information indicating the percentage of energy already consumed in relation to the set consumption target.

- Tips and advice

Tips and advice are short, simple text messages that help users understand how to save energy. To be effective, tips must be personalized, reliable, relevant, and related to both consumption and user motivation (Darby 2006; Ueno et al. 2006; Roberts et al. 2004; Vassileva and Campillo 2014; Yun et al. 2015). Social networks, such as Facebook, can also be used to share tips and motivate users to take immediate action (Suppers and

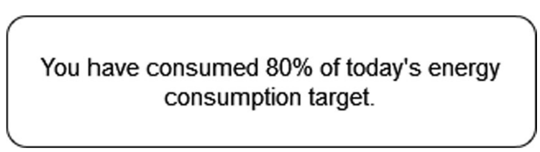


Fig. 4 Goals and targets

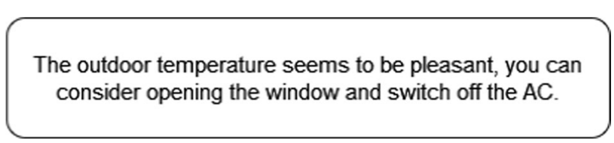


Fig. 5 Tips and advice

Apperley 2014). Figure 5 provides an example of advice that suggests switching off the air conditioner (AC) when not required, to save energy.

- Incentives: Reward and penalty

Reward and penalty are motivational strategies used to encourage users to reduce their energy consumption, with users receiving a reward for reducing consumption or a penalty for increasing it (Moura et al. 2019). Since the reward or penalty is announced before the user's action, both are considered incentives. Rewards and penalties can be either economical, such as receiving a fine for exceeding a consumption limit or earning points to exchange for more efficient products, or social, such as the feeling of performing environmentally friendly behaviours for the good of society (Darby 2010; Jain et al. 2012; Abrahamse et al. 2005). Research has shown that users who receive monetary rewards tend to save more energy compared to those receiving social rewards (Abrahamse et al. 2005).

- Information presentation

The format in which feedback is presented is a critical factor that can significantly impact energy savings (Darby 2006; Zvingilaite and Togeby 2015). Feedback can be conveyed in three different formats: numerical (using units such as monetary, energy, or environmental units), analogue (through graphs, charts, dials, gauges, or bars), and ambient (using images, colours, sounds, or lights to provide an overall sense of the

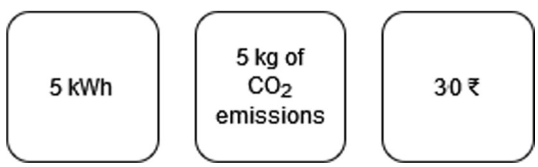


Fig. 6 Numerical formats

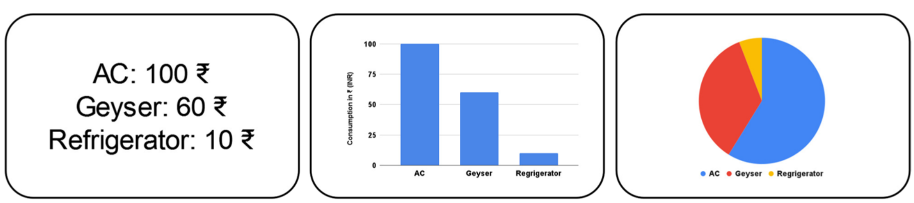


Fig. 7 Analogue formats

Fig. 8 Ambient formats

situation) (Darby 2010; Chiang et al. 2012). Figure 6 displays information in numerical format, Fig. 7 in analogue format, and Fig. 8 in ambient format.

The way information is presented on a device relies heavily on how the user comprehends and perceives numerical, analogue, and ambient data. To facilitate better understanding, a combination of numerical and analogue formats should be employed (Fischer 2008; Roberts and Baker 2003; Karjalainen 2011). While some studies suggest that the information format should be simplistic, this contradicts research indicating that users desire detailed consumption data (Fischer 2008; Anderson and White 2009; Roberts and Baker 2003; Jacucci et al. 2009). Additional research is necessary to determine the most effective and appropriate information formats to use in different contexts. It is crucial to present information in a manner that is easily comprehensible and does not lead to doubts or confusion.

To create an effective energy feedback interface, it is crucial to have a thorough understanding of user preferences regarding the feedback frequency, feedback medium, and the type of information provided. Research has shown that user preferences for these parameters vary across different age groups. As an example, a study (Moura et al. 2019) discovered that children, young adults, and older adults have unique preferences for energy feedback interface design. In response, interface prototypes for In-Home Display (IHD) were created for each age group. It has become increasingly apparent to researchers that user preferences must be considered when designing feedback interfaces.

To accommodate different user profiles, combining various visualization techniques is recommended (Chalal et al. 2022). While eco-feedback systems offer visualization, they may not be sufficient on their own to instigate behavioural change. This issue is multifaceted, with factors such as psychological, socio-economic, technological, methodological, and personal qualities and preferences of end-users at play (Chalal et al. 2022). Therefore, designing the same interface for all users by combining various visualization techniques may not be an ideal approach. Instead, careful selection of visualizations is crucial to facilitate behavioural transformation among end-users (Al-Kababji et al. 2022). Therefore, our work includes taking preferences from two focused groups and designing interface prototypes for them.

Methodology

In this section, we provide an overview of our data collection, the statistical technique used for analysis, and the design and validation of our user interface. This methodology is based on the theory-based taxonomy for feedback interface design (Albizri 2020).

Data collection

It is important to gain a clear understanding of people's preferences before attempting to develop effective ICT-based energy conservation programs (Dane et al. 2020). Surveys are a good means to gain a better understanding about user preferences before actual implementation. A questionnaire-based survey was thus designed to identify users' preferences for the information types and information presentation formats (numerical, analogue, and ambient) identified in the literature review.

Our questionnaire was designed to include multiple-choice questions with single or multiple select answer types, and was divided into nine distinct sections. The sections were organized as follows:

1. Study Instructions: This section included a welcome note, a consent form, and basic information about the research.
2. Demographic Details: This section included questions to obtain demographic information such as gender, age, education level, income, and occupation.
3. Energy Literacy: This section included questions to assess the user's level of knowledge about energy consumption.
4. Electricity Feedback: This section included general information about what feedback is, along with an example. It also included questions to determine user preferences regarding the medium and frequency of energy feedback.
5. Electricity Feedback Interface: This section included general information about the feedback interface, along with an example of how a feedback interface looks like.
6. Electricity Consumption: This section included questions to determine user preferences for the types of information presentation such as monthly/weekly or in terms of kWh/₹.
7. Electricity Performance: This section contains questions aimed at determining the user's preferred indicators (such as emojis, speedometers, colours, etc.) and presentation formats (text, graphs, charts, etc.) that would be most helpful in improving the overall energy performance of their house.
8. Rate the Importance of Each Information Type: This section included questions to determine the importance of each type of information (such as real time consumption, comparison with past consumption) for users.
9. Thank You Note: This section included a thank you message to the user for their participation in the survey.

By organizing the questionnaire in this manner, we aimed to obtain comprehensive data on user preferences for energy consumption feedback.

Participants for the study were recruited from two age groups: young adults and middle-aged adults. Due to concerns regarding consent and awareness, individuals under the age of 18 were not included in the survey. However, there was limited participation from older individuals, aged 45 years and above, possibly due to their lower interaction with digital devices and smartphones. As a result, the study focused on two age groups: young adults (aged between 18 and 24 years) and middle-aged adults (aged between 25 and 45 years). A total of 446 participants (190 young, Male = 140, Female = 48, Prefer not to say = 2 and 256 middle-aged, Male = 152, Female = 104) completed the online survey, which took approximately 10–20 min to finish. Participants were recruited through online circulation of the survey link via email and social media groups, leveraging the networks of students and parents in the IIIT-H community. To ensure a diverse range of responses, participants were encouraged to share the survey link with their friends and acquaintances. Prior to completing the questionnaire, participants provided their consent for participation in the study.

Data analysis

Both descriptive and inferential statistics were used to analyse the data. Descriptive statistics were employed to summarize the data using frequency distribution tables and bar charts. The frequency distributions were converted into percentages and represented graphically to facilitate interpretation of the results. To test the statistical significance of the findings, inferential statistics tests were conducted. Since the questionnaire response included nominal data, non-parametric statistical tests were used. Specifically, a Chi-Square Test of Independence was performed to evaluate the relationship between the two age groups and their feedback information preferences. The JASP statistical software was used to analyse the data.

Interface design

Following the analysis of the results using descriptive and inferential statistics, prototypes of mobile application interfaces were designed for both age groups using Adobe XD software.

Design validation

To validate the designed interface screens, a follow-up survey was conducted with the same focus group. Only those participants who had provided their email addresses in the first survey were invited to participate in this subsequent study. The questionnaire featured single-option select multiple choice questions, with each question asking for the participants' preferences for the prototypes designed for the top five types of information favoured by the users: total energy consumption, appliance-level disaggregated information, tips, goals, and historic consumption comparison. A total of 27 participants (13 young adults and 14 middle-aged adults) took part in the second survey.

Results

In this section, we analyse the user preferences of different types of information among young and middle-aged adults. The presented results are ordered based on the critical parameters of energy feedback outlined in the literature review. The following are the findings obtained from the survey.

Feedback frequency

The participants were asked to select (single option select type question) their preferred frequency of receiving energy consumption feedback from the following options: daily, weekly, or monthly (Fig. 9).

The survey results showed that participants preferred monthly feedback over more frequent feedback. However, there was a notable difference between young and

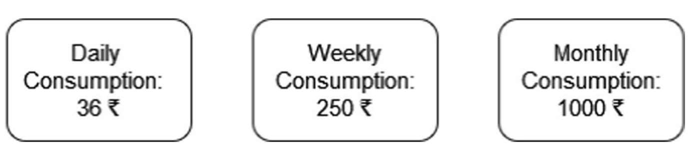


Fig. 9 Options for feedback frequency

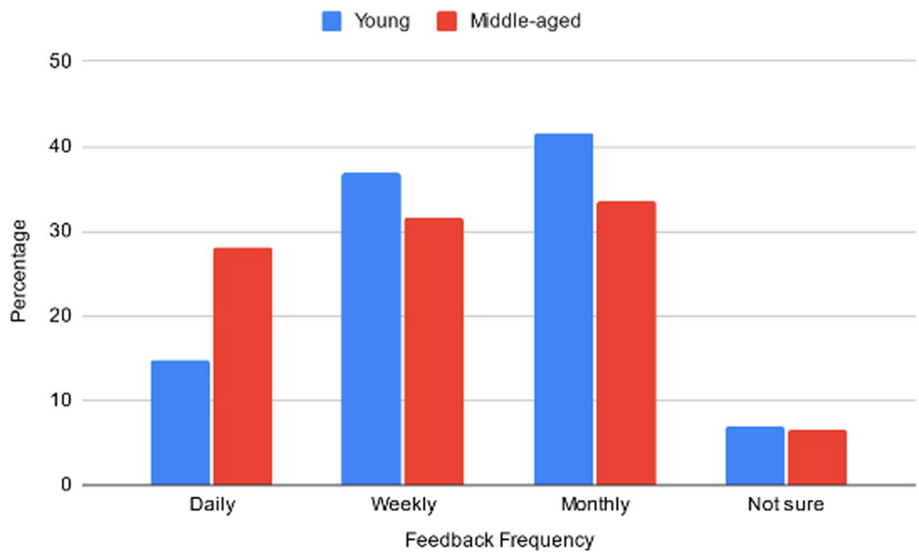


Fig. 10 Feedback frequency

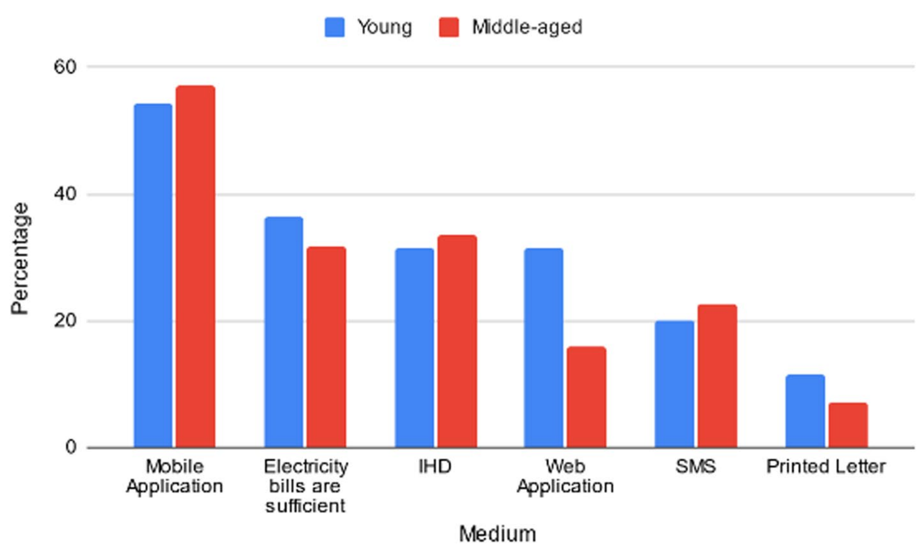


Fig. 11 Feedback medium

middle-aged adults regarding daily feedback preferences, with middle-aged adults showing a greater preference for daily feedback (Fig. 10). The Chi-Square test confirmed a significant difference between the two age groups, $^{X2}\ X^2(3, N = 446) = 11.476$, $p = 0.009$, indicating that middle-aged adults were more likely to choose feedback with a daily frequency.

Feedback medium

The participants were asked to select (multiple option select type question) their preferred medium for receiving energy consumption feedback from the following options:

mobile application, in-home display (IHD), paper bills, and others (Fig. 11). The results showed that in both the age groups, the majority of participants preferred using a mobile application for energy feedback compared to IHDs, paper bills, or other mediums.

Type of information

In the survey, users were requested to rate the significance of information types in the feedback interface based on a scale of 1–5, where 1 indicates "not important" and 5 indicates "very important." The choices given to the participants were: (1) Total consumption of the house, (2) Consumption of each appliance, (3) Energy-saving tips, (4) Goals, (5) Past energy comparison, (6) Real-time consumption, (7) Consumption of each room, and (8) Comparison with neighbours.

Based on the ratings given by participants, the top five information types preferred by both age groups are total energy consumption, appliance-level disaggregated information, energy-saving tips, goals, and comparison with past consumption, as shown in Fig. 12. The interface prototypes for the mobile application were designed for these top five information types to limit the number of screens. It is worth noting that comparing energy consumption with neighbours was the least preferred information type for both age groups, which is an important finding in the Indian context as previous research has emphasized the effectiveness of normative feedback in promoting energy savings.

The three information presentation types were further surveyed to understand user preferences.

- Numerical presentation types

Users were asked to rank their preferred type of numerical presentation, choosing between monetary, energy, and environmental units. As shown in Fig. 13, both age groups equally prefer to see their consumption presented in monetary terms, i.e., in Indian rupee (₹) units. The Chi-Square test showed in-significant difference between

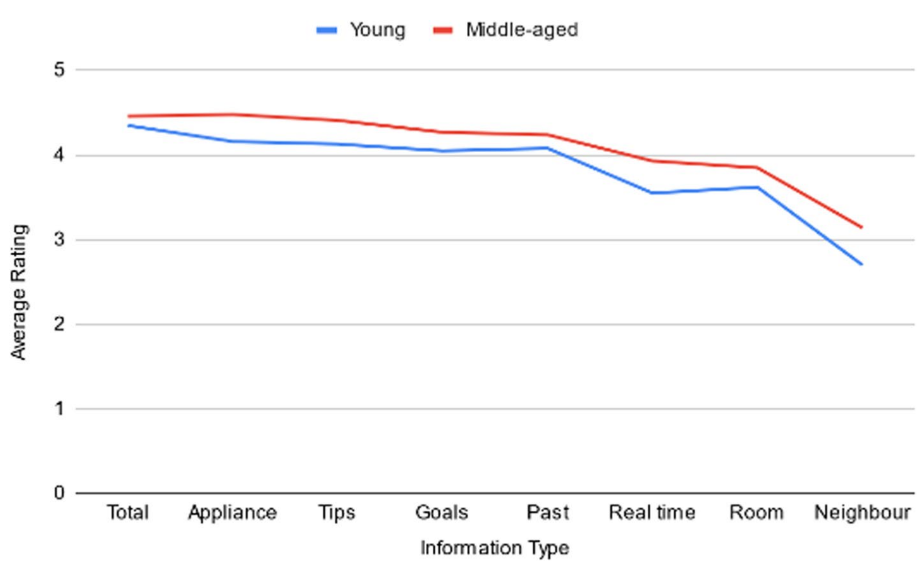


Fig. 12 Type of information

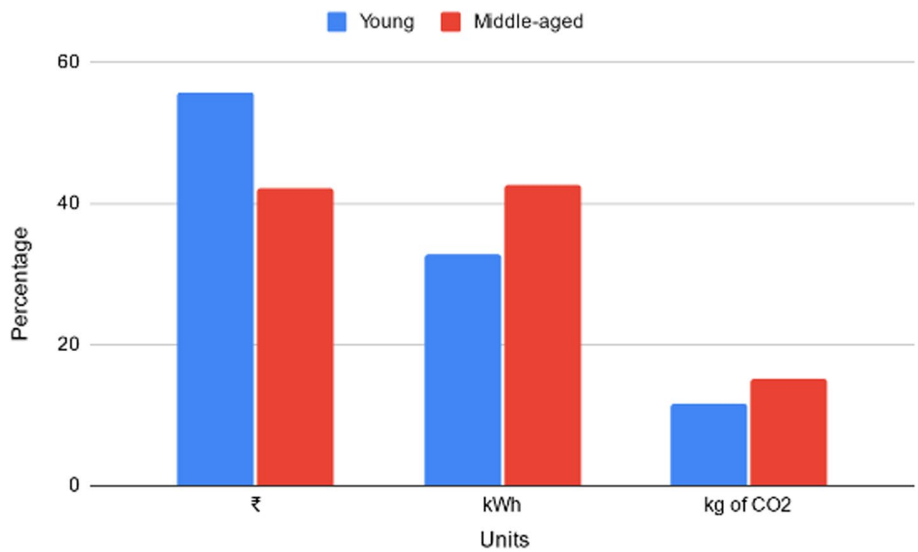


Fig. 13 Numerical presentation types

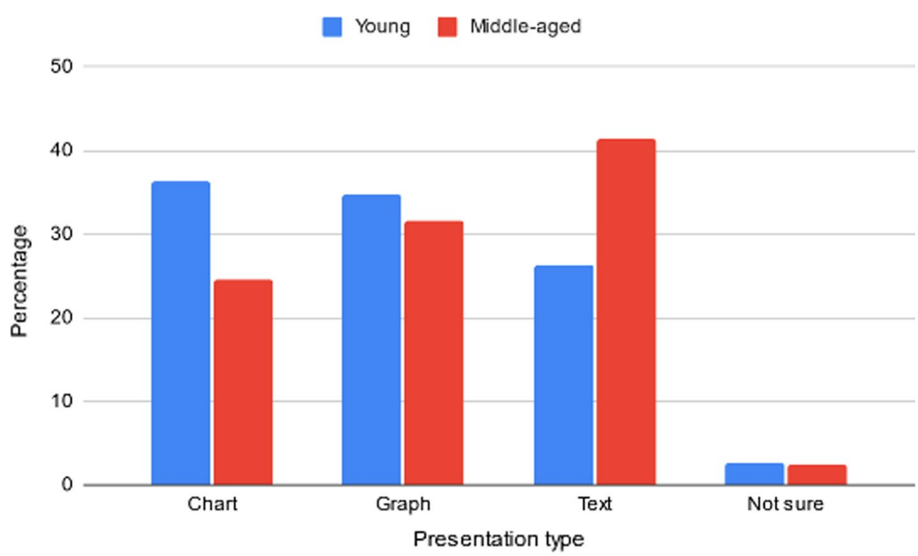


Fig. 14 Analogue presentation types

the two age groups, $X^2(2, N=446)=8.085$, $p=0.018$. However, the middle-aged group showed equal preference for kWh units, which could be because the middle-aged group is more responsible for paying their household electricity bills and are more aware of the energy units.

This is supported by the participants' responses to questions about their energy literacy. About 29% (55/190) of the young age group participants responded affirmatively to the question "Do you personally pay the electricity bill for your house?", whereas about 62% (158/256) of the middle-aged group participants responded affirmatively. Similarly, about 60% (114/190) of the young age group participants and about 68% (174/256) of the middle-aged group participants responded affirmatively to the question "Does 1 unit of electricity mean the same as 1 kWh of electricity?"

- Analogue presentation types

The participants were asked to select their preferred presentation type between chart/graph and text. According to Fig. 14, it appears that middle-aged citizens prefer text-based feedback instead of feedback presented in the form of a chart or graph. This preference could be due to the fact that some types of charts and graphs require more time to comprehend. As per the principles of cognitive science, the lesser the conceptual load on the screen the easier it is for the user to understand the information (Sweller 2011). However with age the capacity to handle this cognitive load decreases (Korotkevich et al. 2015) and probably that's why middle-aged citizens prefer a less informative display. The Chi-Square test results revealed a significant difference between the two variables, $X^2(3, N=446)=12.504$, $p=0.006$.

- Ambient presentation types

The participants were asked to rank various ambient presentation types according to their preferences. Based on the Chi-Square test results (X^2 $(3, N=446)=3.372$, $p=0.338$), there was no significant difference found between the two variables. As shown in Fig. 15, both age groups indicated a preference for Emoji/Smiley ambient presentation types over any other option. As a result, the designed prototypes included happy and sad emojis to illustrate good versus bad consumption behaviour.

Interface Design

The results indicate that the majority of participants preferred using a mobile application as their energy feedback medium over IHD or any other option. We developed mobile application screens specifically tailored to the preferences of the two age groups. Young

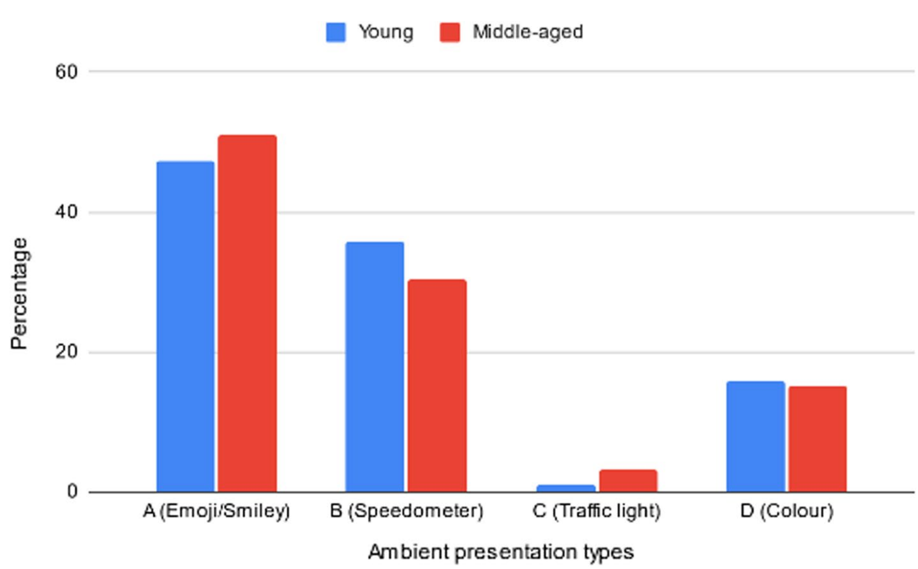


Fig. 15 Ambient presentation types

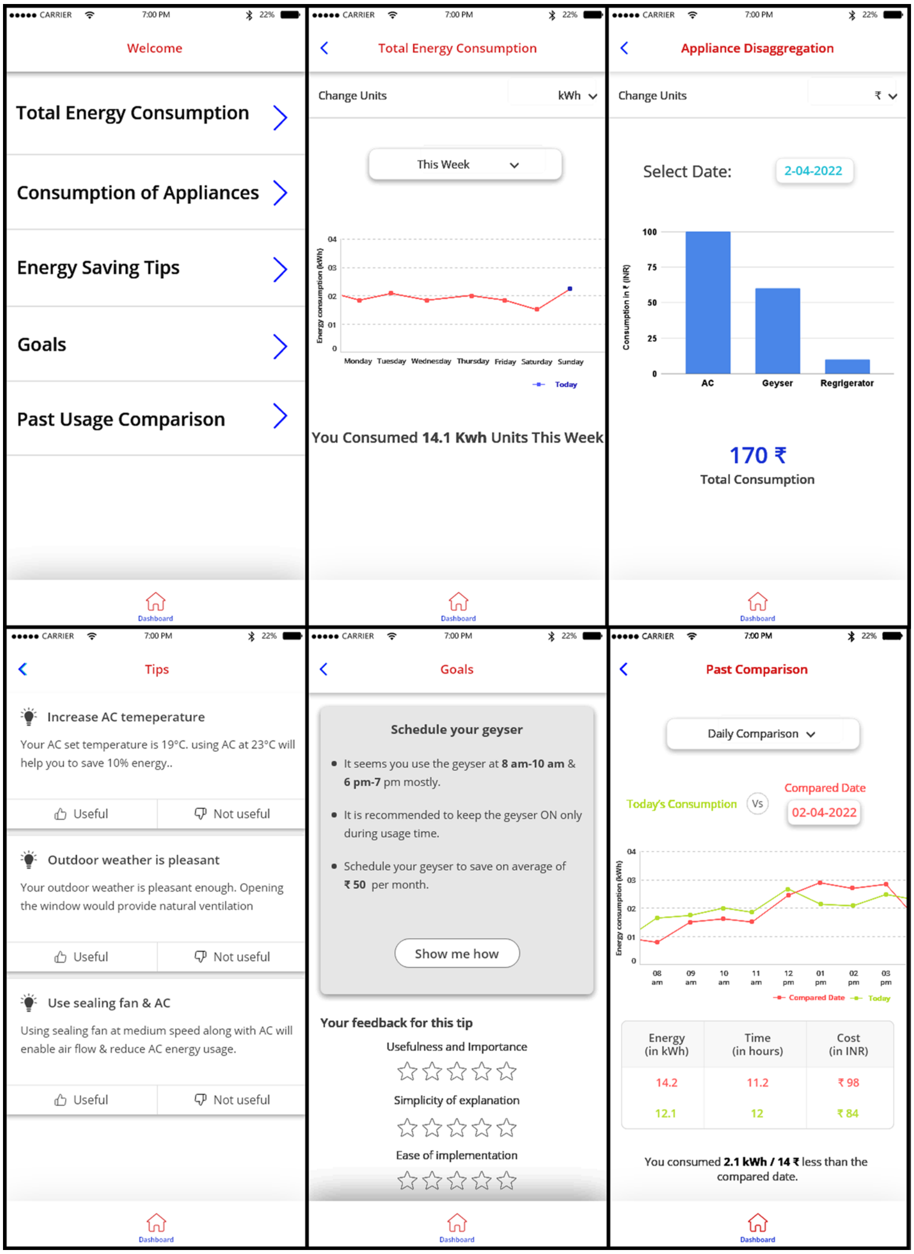


Fig. 16 Mobile application interface prototypes for the young adults

adults indicated a preference for more detailed information, including delayed feedback frequency and energy information in monetary units. As shown in Fig. 16, the mobile interface design for young adults reflects these preferences.

In contrast, middle-aged adults favoured simple text-based feedback with minimal information, including energy consumption displayed in both monetary and energy units. Figure 17 illustrates the mobile interface design catering to the preferences of middle-aged adults. Figure 18 displays some alternate screen designs that cater to the similar preferences of both age groups.

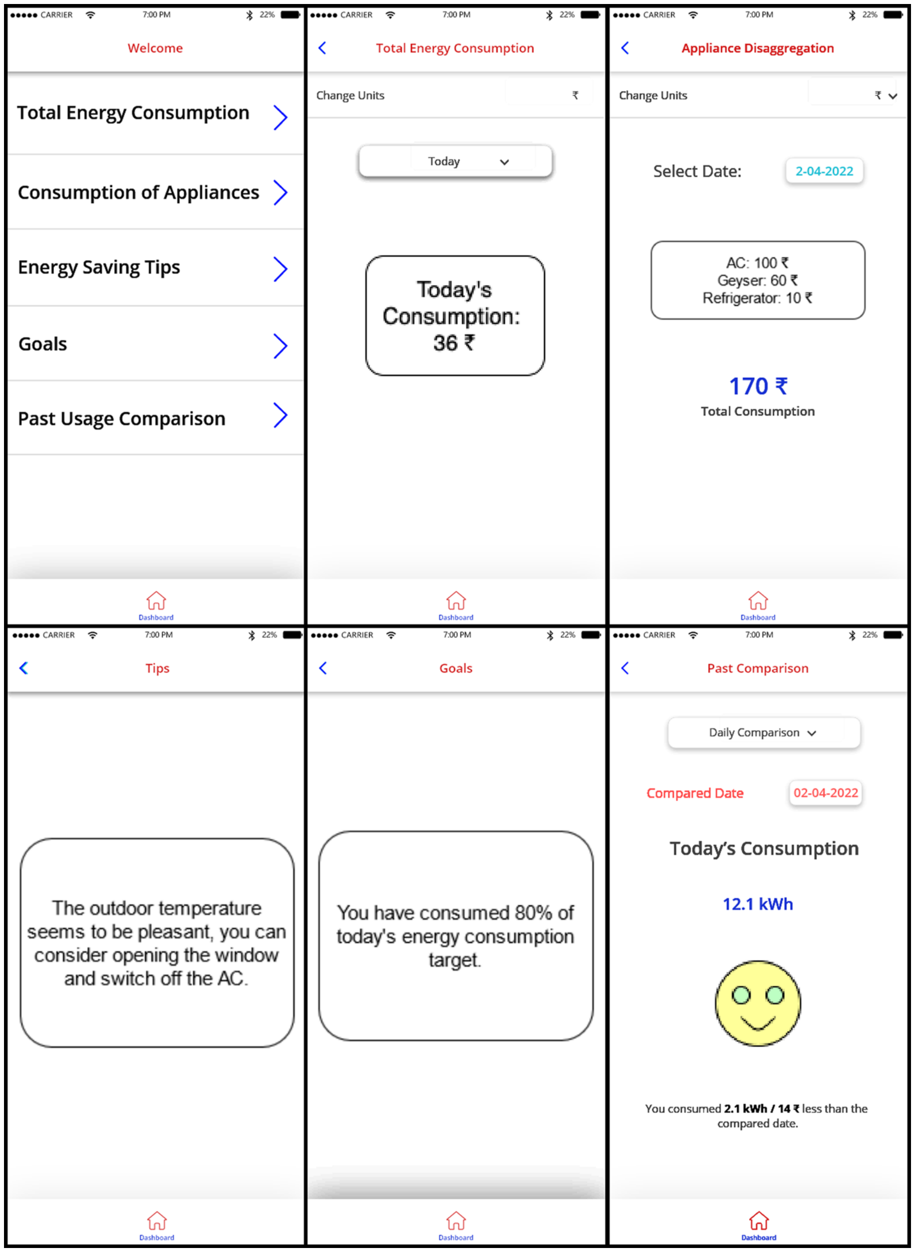


Fig. 17 Mobile application interface prototypes for middle-aged adults

Design validation

Participants of the first survey who opted for future participation validated the interface designs demonstrated above. Two hundred fifty-six participants received an email for participation in the second survey, out of which twenty-seven participants participated. These participants were presented with various screens featuring different combinations of information and presentation types and were asked to select their preferred design.

The first question in the second survey asked participants to compare options for displaying the total energy consumption of their residence. Figure 19 displays the various options presented to participants, which included different combinations of

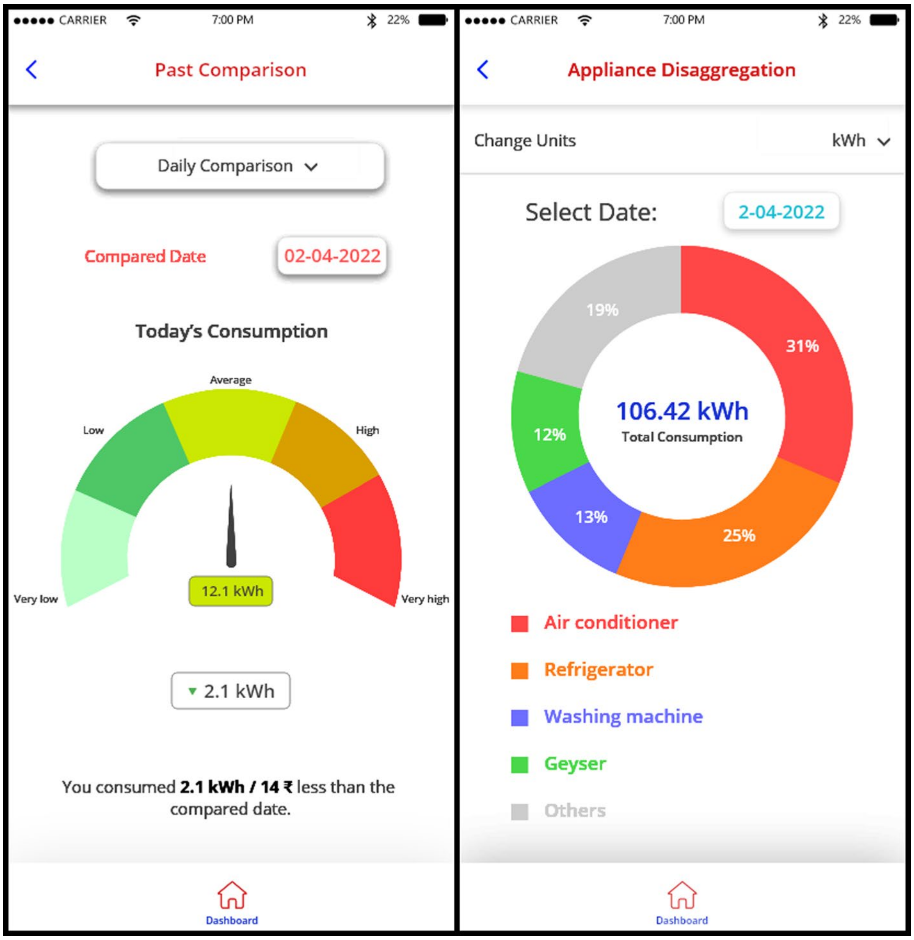


Fig. 18 Generalized screen designs

daily/weekly feedback frequency, energy/monetary units, and text/graph forms of information presentation. While the first survey results suggested that young adults preferred graphs over text for feedback, the second survey results (Fig. 20) indicate that both age groups preferred option B. This could be because the graph in option A was too complex and difficult to understand, even for young adults. Participants provided feedback indicating that the graphs were challenging to comprehend, such as: "The graphics could be better in the options I have selected. The simpler, the better. Nobody wants to spend time looking at one more app or interface," and "Some graphs are difficult to understand".

The second question in the second survey asked participants to compare options for displaying appliance-level disaggregated information. Figure 21 displays the options presented to participants, which included text, graph, and chart forms of information presentation. The results showed that young adults preferred option B with a graphical presentation, while middle-aged adults preferred option C with a more generalized display (Fig. 22). It can be observed that, by simplifying the graphs, the preferences of users in both age groups shifted away from basic text-based feedback, as seen in the first question.

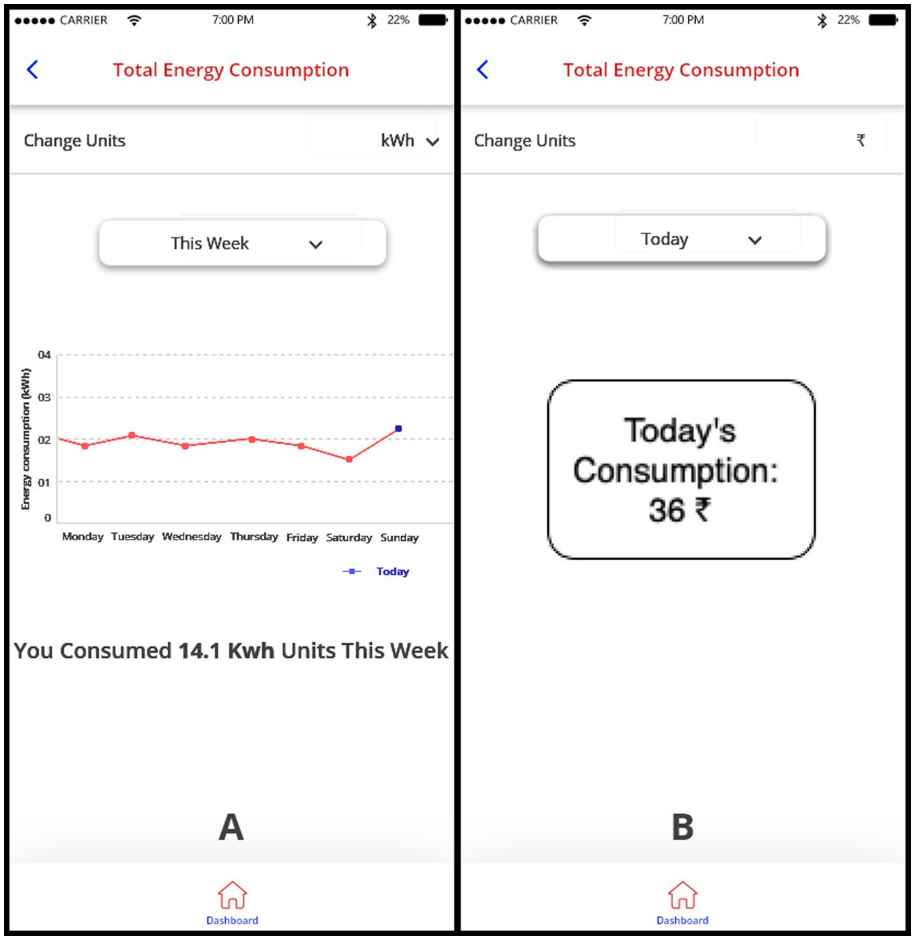


Fig. 19 Options for showing total energy consumption. **Option A**: Detailed feedback with line graph, **Option B**: Simple text based feedback

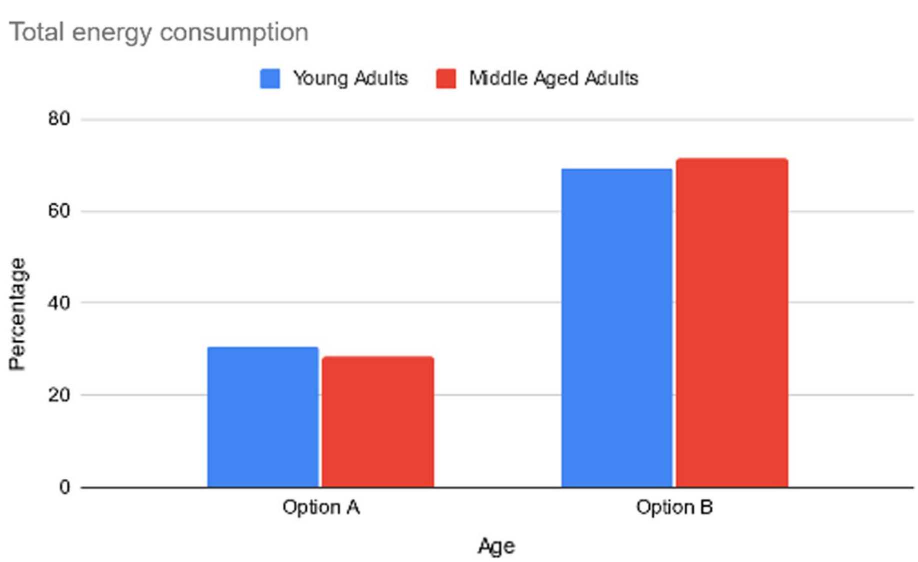


Fig. 20 Validation results for total energy consumption

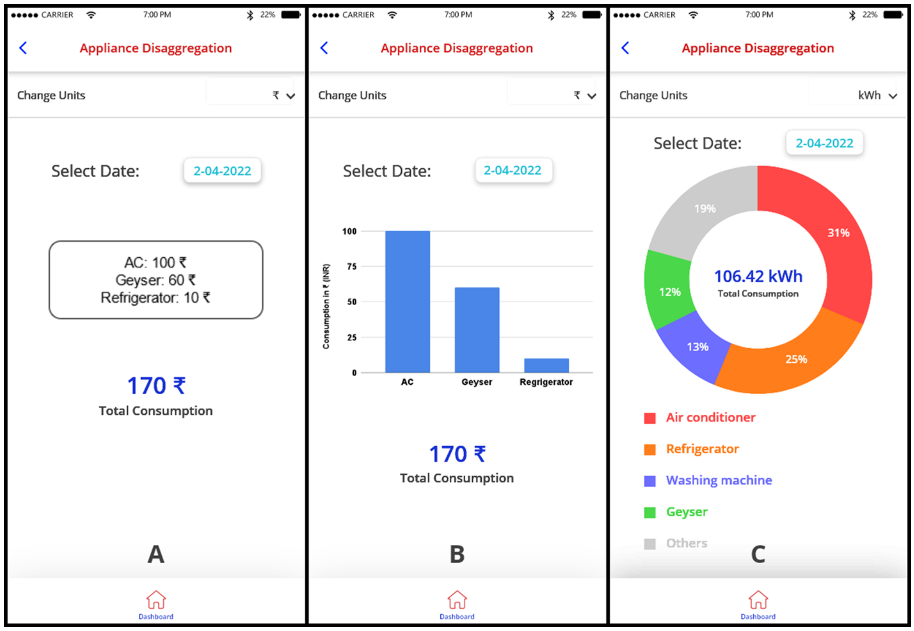


Fig. 21 Options for showing disaggregated consumption. **Option A**: Text, **Option B**: Graph, **Option C**: Chart, forms of information presentation

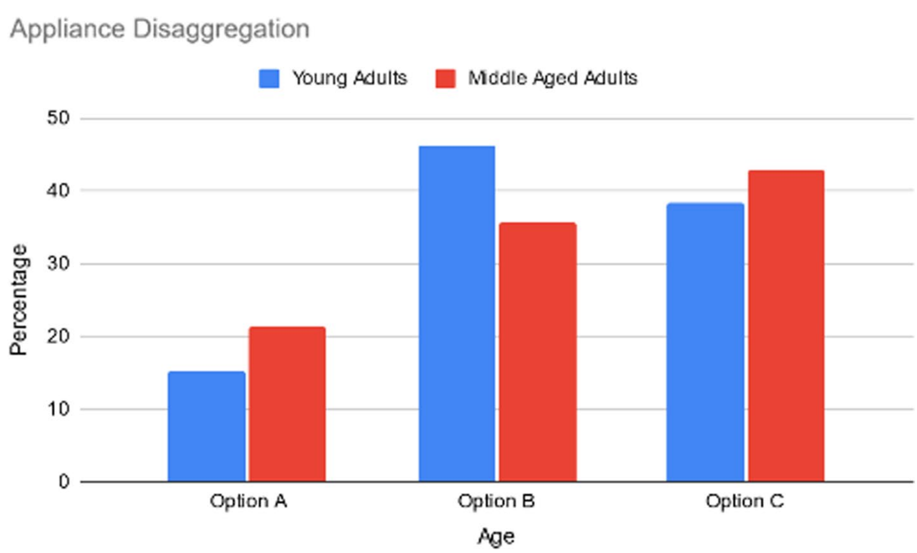


Fig. 22 Validation results for disaggregated consumption

The third question in the second survey asked participants to compare options for displaying energy-saving tips to users. Figure 23 displays the options presented to participants, which varied in the amount of information displayed on the screens. The results (Fig. 24) indicated that middle-aged adults preferred option B with a very simple text-based screen, while young adults preferred option A with a more informative screen. This suggests that young adults prefer a more informative display, while middle-aged adults prefer a more streamlined, less cluttered presentation.

The fourth question in the second survey compared options for displaying energy-saving goals/targets to users. Figure 25 displays the options presented to participants, which

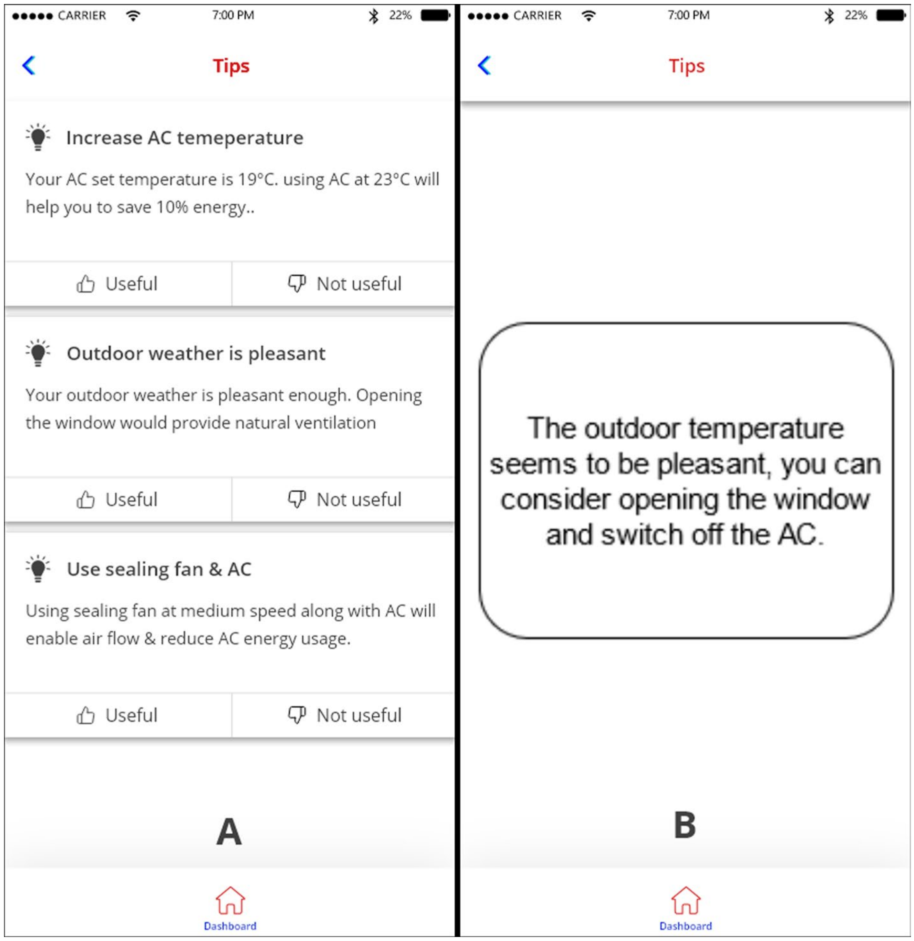


Fig. 23 Options for showing tips. **Option A**: Detailed more informative feedback, **Option B**: Simple text based feedback

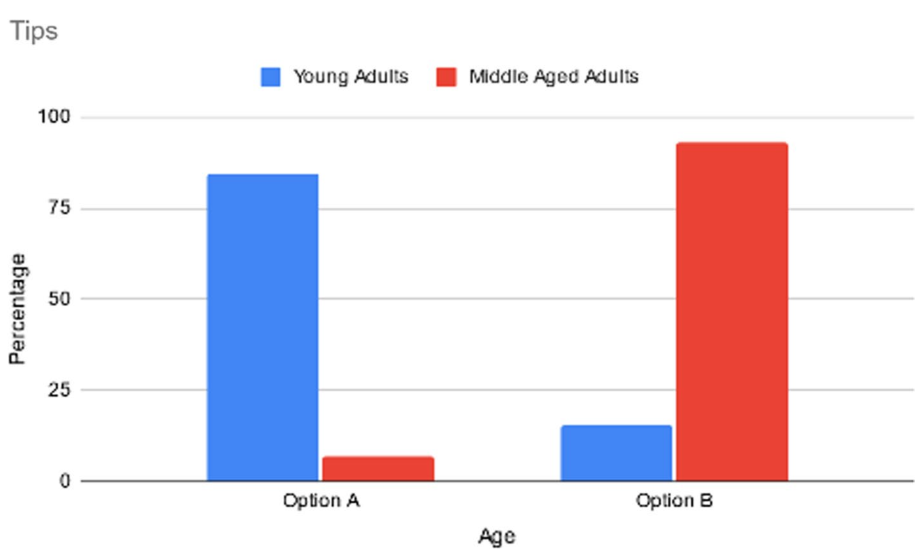


Fig. 24 Validation results for tips

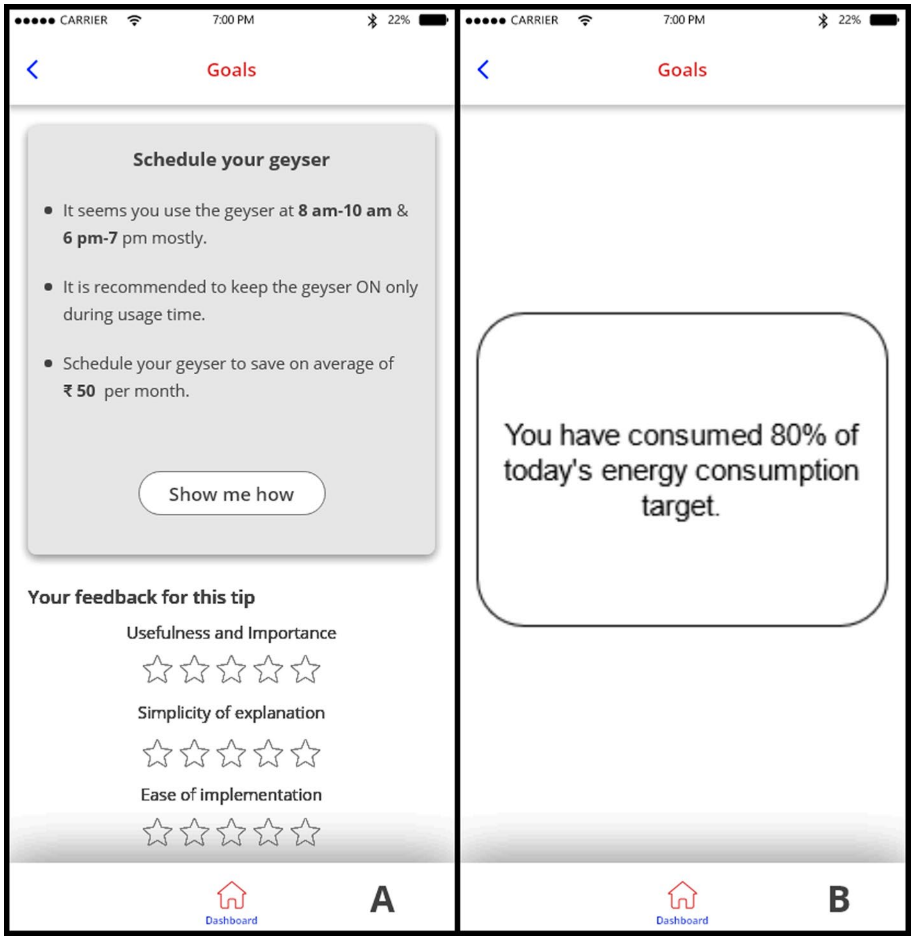


Fig. 25 Options for showing goals. **Option A**: Detailed more informative feedback, **Option B**: Simple text based feedback

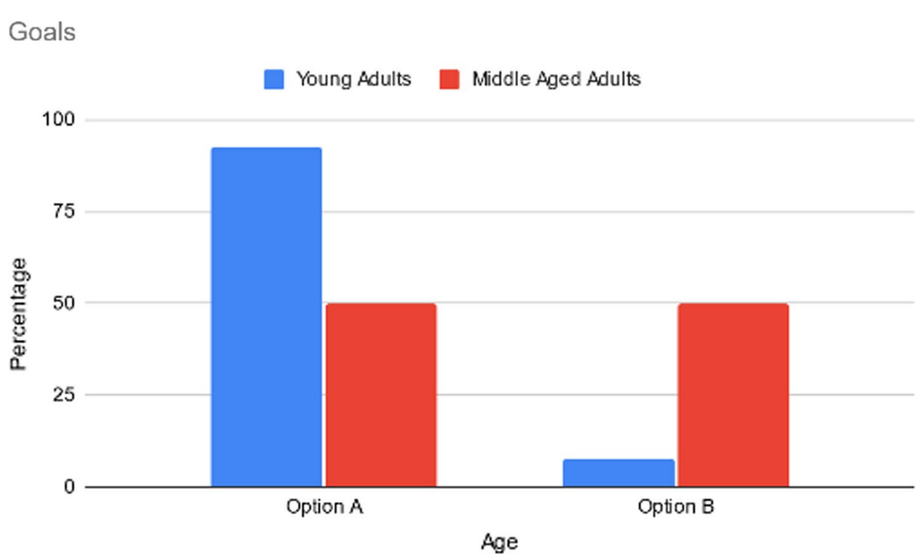


Fig. 26 Validation results for goals

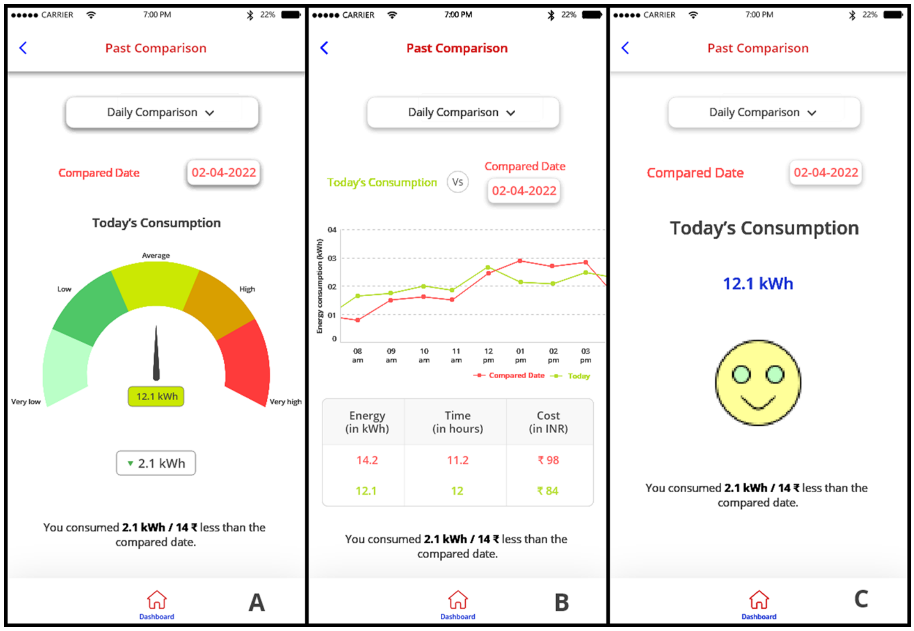


Fig. 27 Options for showing past consumption. **Option A**: Use of Speedometer as ambient information presentation type. **Option B**: Detailed more informative feedback including graph and table, **Option C**: Simple text based feedback with use of Emoji as ambient information presentation type

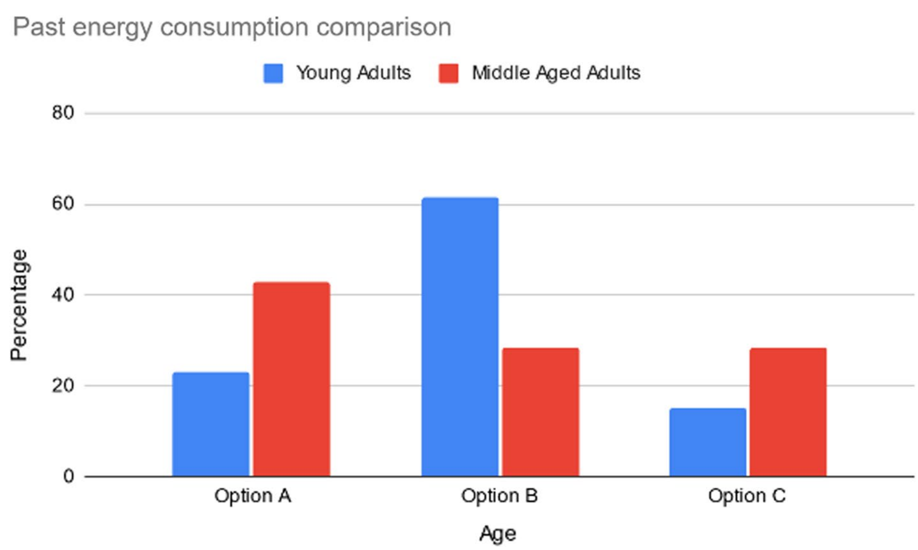


Fig. 28 Validation results for past consumption comparison

also varied in the amount of information displayed on the screens. The results (Fig. 26) showed that young adults preferred option A with a more informative goal, while middle-aged adults were equally split between the two options. This further supports the idea that young adults prefer a more informative display.

The final question in the second survey compared options for historic energy consumption comparison. Figure 27 displays the options presented to participants, which compared the use of ambient presentation types and the amount of information displayed on the screens. The results (Fig. 28) showed that young adults preferred option B with more informative feedback, including a graphical comparison and a table to show the compared data. Middle-aged adults, on the other hand, preferred option A with a more streamlined, generalized display and the use of a speedometer ambient information presentation type.

Discussion

To achieve energy savings through feedback, it is crucial to consider how users respond to the provided information. This response is influenced by several factors, such as users' knowledge of energy, understanding of the feedback, and their preferences for taking action. Thus, it is necessary to focus on these factors to ensure that feedback effectively directs users towards energy-saving actions.

Based on the literature review and our survey, it is evident that people have different preferences and driving factors when it comes to taking actions based on feedback. The survey results indicate that middle-aged adults tend to prefer simple, text-based feedback, while young adults prefer more informative feedback in the form of charts and graphs. Cost was found to be the primary driving factor for both age groups, with both preferring to see energy consumption in terms of monetary units rather than energy or environmental units. However, middle-aged adults expressed an equal preference for viewing consumption in energy units, which can be attributed to their greater responsibility for paying electricity bills and better understanding of energy units as indicated by their responses to energy literacy question.

Additionally, it is worth noting that both age groups preferred emoji/smiley types of ambient information presentation. This could be attributed to the widespread use of emojis and smileys in everyday messaging across all user types. Furthermore, both age groups showed a preference for monthly feedback, with middle-aged citizens showing a slight preference for daily feedback compared to young citizens. The chi-squared test results showed a significant difference, more research is required to understand why middle-aged citizens prefer daily feedback.

The survey results also revealed that total energy consumption, appliance level disaggregated information, tips, goals, and historic consumption comparison are the top five information types considered important by the participants. On the other hand, normative comparison was the least preferred by both age groups, even though it is highly preferred internationally. More research is necessary to understand why normative comparison is not preferred by Indians.

It is clear from the results of the design validations for feedback screens related to goals and tips that young adults prefer more informative feedback compared to middle-aged adults. However, when it comes to screen designs for total energy consumption and disaggregated consumption, the validation results suggest that even young adults prefer text-based feedback if the graphs designed are not simple and easy to understand. Therefore, graphs are preferred if they are presented in a simple format. The simplicity of feedback is crucial in effectively presenting any type of feedback information.

It is crucial to understand that user preferences for energy feedback interfaces can vary, even if someone falls in a particular age or demographic group, they still can have different preferences as compared to those in the group. User preferences and driving factors change over time, so one constant display design cannot work for everyone. To achieve long-term energy savings through feedback, we suggest researchers to develop customizable interfaces that can adapt to changing user preferences. The design should be such that it maintains a balance between not showing too much information on the screen and showing enough options for the users to choose basic preferences like units of consumption and frequency of consumption.

When designing an interface, it is crucial to prioritize user engagement. One way to achieve this is by incorporating dynamic elements that capture the user's attention and maintain their interest over time. To achieve this, designers must continuously evolve their design and explore creative approaches, including analogue and ambient presentation types, to create visually interesting screens. By doing so, users will be more likely to engage with the interface. To avoid monotonous screens, the designs should also change over time. A static display can quickly become boring, but a dynamic and evolving design will keep users interested and coming back for more. Future research can focus to assess user engagement with the designed screens.

Machine learning and artificial intelligence techniques can play a significant role in learning from past user actions, their preferences and providing personalized feedback. Future research should focus on developing such dynamic customizable interfaces to maximize energy savings by engaging users effectively.

Limitations

The findings of this study have to be seen in light of some limitations. Due to low participation in elderly age group (45 years and older age), the survey analysis was conducted in young and middle-aged groups only. Future work can target more on how to involve elderly age people to participate in the survey. Knowing their understanding and preference for feedback would benefit the research community.

Energy consumption patterns may vary considerably across different regions in India. While participants from all parts of the country were included in the survey, the study did not capture the unique preferences and behaviours of users in each region. Future research could consider conducting more targeted surveys or interviews in specific regions or communities to gain a more comprehensive understanding of regional differences in energy consumption patterns and preferences.

The prototypes presented in the study were designed on hypothetical data, and not tested in real-world scenarios. While they provide valuable insights into potential design solutions, their effectiveness in practical applications is unknown. To address this limitation, future work could involve the actual implementation of the designs with real-time data to evaluate their effectiveness in improving energy consumption behaviour.

Conclusion

This study aimed to design mobile application interfaces that can increase energy savings through effective feedback. We examined the user preferences for energy feedback in the Indian context based on focus groups with 446 participants (190 young and 256 middle-aged), using a questionnaire-based survey. We analysed the survey responses using the Chi-Square Test of Independence to determine the relationship between user preferences for feedback information and age groups. Our findings reveal that:

- The top five information types considered important by participants are total energy consumption, appliance level disaggregated information, energy-saving tips, goals, and historical consumption comparisons. Conversely, normative comparison was the least preferred information type.
- While young adults prefer to see consumption information in monetary terms, middle-aged and elderly citizens equally prefer to view their consumption in both kWh units and ₹ units.
- Middle-aged citizens prefer text-based feedback over feedback presented in the form of a chart or graph.
- Both age groups prefer presentation in form of Emoji/Smiley over any other ambient presentation type.

Based on research findings, we designed mobile application interface prototypes that meets users' preferences for feedback information. We further validated the designed prototypes with 27 participants from the same focus groups, comprising 13 young adults and 14 middle-aged adults. The results from the design validation survey support our initial survey findings, indicating that young adults prefer a more detailed and informative display, while middle-aged adults prefer a simpler, text-based display with less information.

The main conclusion of this study is the importance of well-designed feedback that presents information in a simple and easily understandable manner. Participants reported difficulty in reading technical graphs and expressed a preference for text-based feedback. However, when presented with a simpler graph, both age groups preferred it over text-based feedback. Thus, a simplistic design is highly appreciated. By presenting information in a clear and concise manner, we can reduce cognitive load and maintain user engagement with the content. Moreover, it is important to note that user preferences and the factors that drive them to save energy are not static and can evolve over time. Thus, a single display design may not be suitable for all individuals. To ensure sustained energy savings through feedback, we propose that researchers focus on developing customizable interfaces that can adapt to users' changing preferences.

This study is one of the first works done on residential energy feedback interfaces design in the Indian context. The study presents interface design prototypes for the young and middle-aged adult age groups. Future work can include other age groups and actual on-field implementation of these designed prototypes with real data. Additionally, studies could explore how factors beyond age, such as occupation, income, and other demographic characteristics, influence individuals' preferences for energy feedback.

Abbreviations

IHD	In-Home Display
SMS	Short Message Service
AC	Air Conditioner
IIIT-H	International Institute of Information Technology Hyderabad

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Author contributions
MG designed the surveys, collected, analyzed and visualized the data from the surveys, and designed interface prototypes. VG and PS conceptualized and supervised the study. VG also acquired funding and reviewed the manuscript along with PS. RA designed and collected data for the surveys. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets generated during the current study are not publicly available due to ongoing research on the data, data will be documented and open sourced in future. But the data is available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. IRB, Ethics Approval Committee of IIIT-Hyderabad has approved the study. Proposal ID and Number: IIITH-IRB-PRO-2021-03. A consent form was filled by all the participants at the beginning of the survey to participate in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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