Interface Design for Residential Energy Feedback

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by

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CERTIFICATE

It is certified that the work contained in this thesis, titled **“Interface design for residential energy feedback”** by **Madhur Garg,** has been carried out under our supervision and is not submitted elsewhere for a degree.

Date	**Advisor: Dr. Vishal Garg**	**Co Advisor: Prof. Priyanka Srivastava**

To my family and friends

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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. Residential energy feedback is about providing personalized information on household energy use to consumers to encourage energy saving. 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, like IHD, 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). It is assumed that the possibility of energy reduction is high when the provided information matches the user's display preferences.

Despite the growing demand for quality energy feedback in India, we lack research that examines the Indian population perspective on energy feedback display user interface (UI) design. 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, the 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.

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Chapter 1

Introduction

1.1 Motivation and background

Global residential energy consumption represents 10% of total energy consumption. This covers energy used for cooling, lighting, water heating, and appliances. Total energy consumption has increased by 23% in the last decade and is expected to increase another 48% by 2040 (Conti, 2016). The increase in this consumption occurs due to factors such as population increase, economic growth, and the increase in the number of new technologies (eg: smartphones and televisions) (Ehrhardt, 2010). Although several practices have emerged to reduce consumption, such as new and more efficient appliances, growth rates are still high (Chiang, 2015; Wilson, 2015). To reduce residential energy consumption, measures can be taken such as changing building materials and components (eg, double-glazed windows, using stones on the external wall), replacing old appliances with more efficient ones, and promoting a change in the behavior of users. But as per (Fischer, 2008) changing materials and changing devices do not always lead to reduced consumption. One of the causes is the rebound effect, which occurs when the acquisition of a more efficient device leads to more frequent use, not resulting in savings (Berkhout, 2000).

When the user is aware of their energy consumption, behavior change can be achieved (Yun, 2015). However, most users do not know how their behavior can affect energy consumption (Jain, 2012; Mccalley, 2002; Roberts, 2003; Vassileva, 2012; Yun, 2015). The users' lack of knowledge about how to save energy, the consumption of appliances, and the impact of their own behavior makes it difficult to reduce consumption (Fischer, 2008). Behavior has been one of the most studied areas in Psychology (Daae, 2014; Jackson, 2005), in which it is defined as a decision-making process that involves factors (eg, habits, intentions, and socio demographic variables) that shape it, influence, and restrict it (Jackson, 2005; Sopha, 2013). To explain this process, several models have been explored (eg: Ajzeen, 1991; Klockner, 2010), although there is still no consensus on which model is the most adequate to explain the behavior.

To save energy, it is important to make people aware of its use (Darby, 2001; Suppers, 2014; Vassileva, 2013). One way of raising awareness is to present information about energy consumption through electricity bills (Chiang, 2012), but this alone is not enough to save energy. It is necessary that the feedback is provided faster and is easy to understand, with specific information that leads to a reduction (Abrahamse, 2005; Darby, 2006). Feedback is one of the most efficient consequential interventions to achieve reduced consumption (Ehrhardt, 2010). The influence of feedback in the economy depends on the frequency with which it is provided (Chiang, 2012; Darby, 2001). Feedback interfaces provide real-time consumption information, allowing users to associate their pattern of behavior with energy use differently from monthly electricity bills (Chiang, 2012; Darby, 2006; Krishnamurti, 2013; Yun, 2015). While electricity bills can create a 0-10% reduction in consumption, the feedback by devices can reach up to 20% reduction (Abrahamse, 2005; Darby, 2010; Ehrhardt, 2010; Faruqui, 2010; Fischer, 2008; Wood, 2003). 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 feed- back 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 inter- face 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 work 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 review of field-based studies that have evaluated the impact of energy feedback on residential energy consumption, 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. User Interface designs were then made based on statistical significant results of the first survey. The final interface designs were validated with users from the same focus groups using another questionnaire-based survey.

1.2 Problem statement

The aim of this work is to understand: **What are the preferences of Indian users for different feedback information types for displaying residential energy consumption through feedback user interfaces.**

1.3 Contribution to the Thesis

The contributions made by this study in the field of residential energy feedback can be summarized as follows:

- In-depth review of field-studies done on residential energy feedback
- Evaluated the impact of energy feedback on residential energy consumption
- Investigated the information elements on a visual interface that help in understanding the content of energy consumption information for different types of users
- Interface design for residential energy feedback for different types of users (young adults and the elderly) in the Indian context
- Validation of the designed energy feedback user interface prototypes.

1.4 Thesis organization

The rest of the thesis is organized as follows:

- Chapter 2 provides a literature review on residential energy feedback
- Chapter 3 evaluates the impact of energy feedback on residential energy consumption
- Chapter 4 discusses the research method for Interface Design
- Chapter 5 presents the research results of a questionnaire survey carried out to collect data on preferences of users on different types of feedback
- Chapter 6 consists of the proposed conceptual UI design and presents results of the design validation survey. It also discusses the key findings of this study
- Chapter 7 concludes this study and recognizes the significance of the study
- Chapter 8 throws light on the improvements that can be made in future

Chapter 2

Literature review

2.1 Energy feedback

Energy feedback is the information passed on to the user about their energy consumption (eg electricity bills and feedback interfaces). Most users do not understand their own consumption (Burgess, 2008) therefore the feedback can contribute to raising awareness about energy saving (energy literacy) and promoting more sustainable behaviors (Froehlich, 2010).

Feedback is defined as clear and specific information provided to the user right after an action (Darby, 2001). This information contributes to user awareness and to the reduction of energy consumption. Research has shown that the type of feedback plays a significant role in the amount of energy savings achieved through energy feedback (Darby 2006). (Darby, 2001) suggests three different types of feedback: indirect, direct and inadvertent. Direct feedback reports energy consumption in real or almost real time through feedback interfaces that measure energy consumption (Chiang, 2015). Indirect feedback shows the energy consumption through the electricity bill, which may have additional information, such as comparing the consumption itself with that of similar houses (Egan, 1998). In Inadvertently feedback, the user can learn about consumption by association, for example, develop community projects to reduce energy consumption or buy more efficient equipment (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). These three parameters are discussed in more detail, later in this chapter.

2.2 Feedback through interfaces

Feedback interfaces, in this study, refers to In-Home Displays (IHD), Web applications and Mobile applications that show information about the consumption of electricity, water and gas in homes to their residents. These devices have been available since the year 2000, and have advanced over other types of feedback (SMS, energy bills) for presenting detailed information of consumption in real time (Darby, 2010).

The studies using IHDs to display feedback information shows large energy savings. In 21 studies reviewed by (Darby, 2006), the average savings was 15%. In 12 studies reviewed by (Faruqui, 2010), the average was 7%. The difference in savings in different studies may be due to the types of information presented in the device (Chiang, 2014). The information presented on the devices (instant consumption, cumulative consumption, consumption by environment, consumption by devices, historical comparison, normative comparison, consumption target, tips, reward, incentive and penalty) draw the attention of users in different ways, causing people to have different motivations for saving energy (Chiang, 2015; Faruqui, 2010 ; Fischer, 2008; Froehlich, 2009; Wilson, 2015).

As per (Anderson, 2009) the lack of understanding of the meaning of the presented information makes some users lose interest in the device or even end up consuming more energy. Lack of precision of the information i.e displayed consumption value different from the true value, was also mentioned as one of the reasons. (Buchanan, 2014) analyzed 125 reviews of 4 visual devices on the amazon website and found people facing technical difficulties in installing the device. The format for presenting the information shown to the user also influences the reduction achieved (Chiang, 2014). For example, some users in the study by (Anderson, 2009) found using the alarm notifications highly uncomfortable and stopped using it. (Van, 2010) and (Skjølsvold, 2017) also comment on the loss of interest in the device because it stopped providing new information about consumption.

The context of use of the visual device must also be considered. Users who already have low levels of consumption and are aware of their consumption may not be interested in using the device (Abrahamse, 2005). Habits can also be a barrier to energy savings, as users may not be willing to let go of old consumption habits (Hargreaves, 2010). Another barrier is related to the privacy and security of consumption data monitored by the visual device (Hargreaves, 2017). (Van, 2010) and (Chiang, 2015) proposed to increase interactivity with the device to facilitate energy savings. Device's interactivity allows the user to change the types and formats of the information presented and the units. With this, the information can adapt to different user motivations. (Oltra, 2013) indicated that users are interested in using devices to learn about their consumption pattern. The location of the device is important for the user to visualize their consumption and observe when changes occur (Hargreaves, 2010; Wilson, 2015). For example, (Anderson, 2009) and (Fitzpatrick, 2009) state that the visual device must be in the user's preferred room in the home. As per their studies, the kitchen and living room are the most preferred locations. (Van, 2010) suggest that device location should be part of the user's routine, for example, if the user monitors the device's daily consumption before bedtime, then it should stay in the bedroom. (Hargreaves, 2010) also commented that the device must be mobile, allowing users to turn the devices on and off and follow the change in consumption in real time. The place users choose to place the device is also related to the device's design. When they find it aesthetically attractive, they place it somewhere central in the home (Hargreaves, 2010).

There are many factors that affect energy savings, so it is necessary to assess how the feedback works best. There is no one type of feedback that works for everyone. Therefore, this must be adapted according to the type of user, the motivations to reduce consumption and the context in which it is applied (Buchanan, 2014). Thus, it is necessary to evaluate the frequency at which feedback is provided, medium through which it is displayed, and what type of information must be displayed. In the following sections, we discuss these parameters in more detail.

2.2.1. 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 frequent 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.

2.2.2. Feedback medium

There are various ways to provide energy feedback to users, such as In-Home Dis- plays (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 consump- tion (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.

2.2.3. 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 its 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 Figure 2.1.

January, 2023 Consumption: 1000 ₹

Figure 2.1. Total consumption

- **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 provid- ing 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 2.2 provides examples of disaggregated energy consumption at both the appliance and room level, presented in Indian rupees (₹).

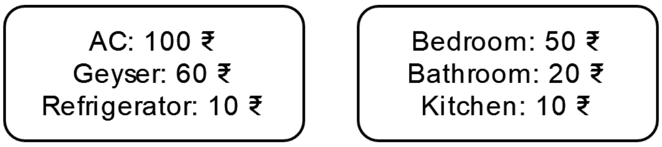

Figure 2.2. Disaggregated consumption

- **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 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 2.3 provides an example of both historical and normative energy consumption comparisons, presented in Indian rupees (₹).

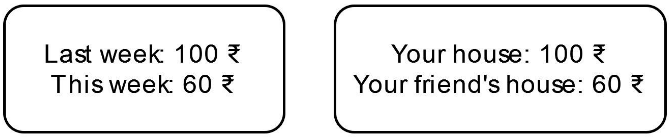

Figure 2.3. Historic and normative comparison

- **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 con- sumption 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 2.4 provides an example of information indicating the per- centage of energy already consumed in relation to the set consumption target.

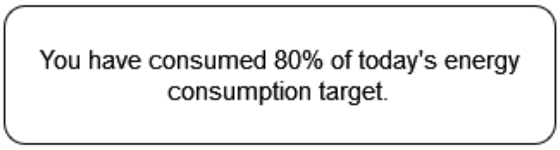

Figure 2.4. Goals and targets

- **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 Apperley 2014). Figure 2.5 provides an example of advice that suggests switching off the air conditioner (AC) when not required, to save energy.

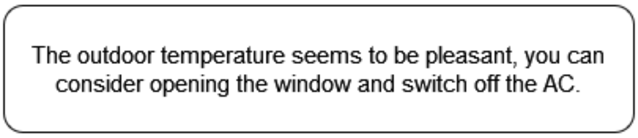

Figure 2.5. Tips and advice

- **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 earn- ing points to exchange for more efficient products, or social, such as the feeling of per- forming 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 situation) (Darby 2010; Chiang et al. 2012). Figure 2.6 displays information in numerical format, Figure 2.7 in analogue format, and Figure 2.8 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 under- standing, 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.

Figure 2.6. Numerical formats

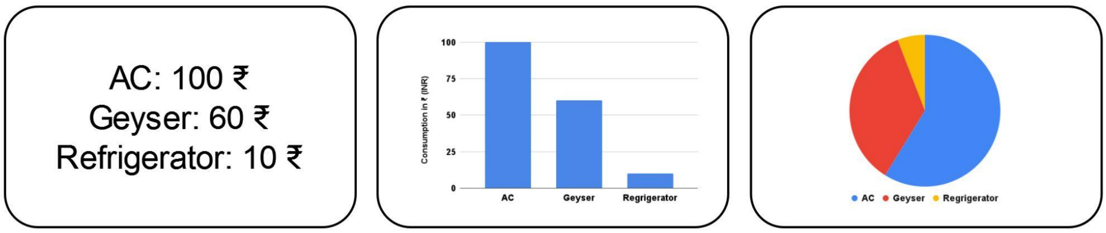

Figure 2.7. Analogue formats

Figure 2.8. Ambient formats

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, methodo- logical, 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.

Chapter 3

Impact evaluation of energy feedback on residential energy consumption

3.1 Introduction

This chapter helps us see the impact of energy feedback on residential energy consumption. It describes the systematic review we carried out to develop a taxonomy for energy feedback based on different characteristics of feedback such as frequency, type, presentation style, and methods of access. It also discusses how energy savings from similar feedback types were found to differ depending on how the study was conducted and what all type of feedback information were provided in different studies including energy units, energy cost and tailored information conducted across diverse audiences (ethnicity, geographical positioning), varying experimental types (longitudinal, Randomized Control Trial) and, size and duration of the studies.

3.2 Feedback Characterization

To assess the impact of energy feedback on savings, we conducted review that focused on studies meeting the following criterias:

1. Residential field studies should have been conducted in occupied homes. Any lab-based simulation, or modeling-based studies were excluded.
2. Field studies should not have any automatic control of devices based on the feedback.
3. The study must have monitored energy consumption of the complete household or at least a set of appliances. All the households involved in the study must have individual energy metering/ billing provisions. Dormitories and hostels were excluded.
4. Results of the study must demonstrate the effect of feedback on the overall household energy consumption, with either absolute or relative savings. Studies designed only to know the impact of feedback on occupant's energy literacy or occupants perceived/ self reported energy savings were excluded.

The collected field study papers were categorized to build a classification hierarchy on feedback types. Table 3.1 **s**hows a summary of the reviewed in-scope studies, comparing the effects of size and duration of studies with the energy savings results obtained. It also tells about different mediums through which feedback was provided and about how savings were calculated.

Table 3.1 Categorization Table

S. No	References	Title	Energy vector	Region of study	Household type	Feedback Information includes	Type of Visualization	Data collection frequency	Frequency of feedback	Size of trial (No. of households)	Duration of study	Medium(s) of feedback	Longitudinal/ Randomized Control Trial	Average Energy Savings (%)
1	McClelland, L., 1979	Energy Conservation Effects of Continuous In-Home Feedback in All-Electric Homes	Electricity	Carrboro, North Carolina	Identical construction*	1.Cost based energy consumption	1. Numeric	*Detail not available	Real time	25	11 months	Panel*	Longitudinal	12
2	Midden, 1983	Using feedback, reinforcement, and information to reduce energy consumption in households: A field-experiment	Electricity, Gas	Voorschoten, Netherlands	Apartments	1. Energy consumption 2. Comparison with previous usage 3. Comparison with neighbors 4. Equivalent monetary rewards for energy conservation 5. Conservation tips 6. Financial consequences of increase or reduction of energy use	1. Numeric 2. Text 3. Graph	Weekly	Weekly	91	12 weeks	Feedback forms	Longitudinal, Randomized Control Trial	19.4 13.8
3	van Houwelingen, 1989	The Effect of Goal setting and Daily Electronic Feedback on In-Home Energy Use	Gas	Nieuwegein, Netherlands	Identical rental houses	1. Gas consumption 2. Energy conservation information	1. Numeric 2. Text 3. Charts (self-monitoring)	Monthly *	Monthly	285	1 year	Paper*	Longitudinal	12.3
4	Arvola, 1993	Billing feedback as means to encourage household electricity conservation: A field experiment in Helsinki	Electricity	Helsinki	Detached houses	1. Electricity consumption 2. Comparison with previous consumption 3. Tips 4. Information on peak hour period	1. Numeric 2. Text 3. Graph	Monthly	10 times a year	696	2.5 years	Letter	Randomized Control Trial	4.7
5	Haakana, M.,1997	The Effect of Feedback and Focused Advice on Household Energy Consumption	Heat, electricity, and water consumption	Southern Finland	*Detail not available	1. Heat, electricity, and water consumption 2. Comparison with historical data 3. Comparison with neighbor 3. Equivalent cost	1. Numeric 2. Text 3. Graph	*Detail not available	Monthly	105	17 months	1. Video 2. Literature (by post)	Longitudinal	21

6	Alahmad, 2002	A Comparative Study of Three Feedback Devices for Residential Real-Time Energy Monitoring	Electricity	Omaha	*Detail not available	1. Electricity consumption 2. Equivalent cost 3. Comparison with historical data	1. Numeric 2. Graph	15 min	Real time	151	30 days	IHD (Aztech)	Longitudinal	12
7	Ueno, 2006	Effectiveness of an energy-consumption information system on energy savings in residential houses based on monitored data	Electricity, Gas	Kyoto, Japan	Detached houses	1. Energy consumption 2. Equivalent cost 3. Tips 4. Appliance wise usage (Upto 18) 5. Comparison with past data	1. Numeric 2. Text 3. Graph	30 minutes	Daily	9	40 weekdays	Laptop computer	Longitudinal	9
8	Benders, 2006	New approaches for household energy conservation-In search of personal household energy budgets and energy reduction options	Electricity, Gas	Netherlands	*Detail not available	1. Information about options for energy reduction	*Detail not available	*Detail not available	*Detail not available	190	5 months	Web based	Randomized Control Trial	8.7
9	Ueno, 2003	Effectiveness of Displaying Energy Consumption Data in Residential Buildings	Electricity, Gas	ECOIS 1: Kyoto, Japan ECOIS 2: Osaka	Detached houses	1. Energy consumption 2. Equivalent cost 3. Tips 4. Appliance wise usage (upto 18) 5. Comparison with past data ECOIS2: 6. Comparison with neighbors	1. Numeric 2. Text 3. Graph	30 minutes	Daily	ECOIS 1: 9 ECOIS 2: 10	ECOIS 1: 40 weekdays ECOIS 2: 28 weekdays	Laptop computer (via email)	Longitudinal, Randomized Control Trial	18 13
10	Abrahamse, 2007	The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents	Electricity, Gas	Groninger, Netherlands	73% Homeowners	1. Tailored energy-saving measures: a. total energy savings b. energy savings per option c. monetary savings 2. Goal setting 3. Comparison with other participants	*Detail not available	*Detail not available	*Detail not available	189	5 months	1. Website 2. Newsletter sent by email	Longitudinal, Randomized Control Trial	5.3 6
11	Van Dam, 2010	Home energy monitors: Impact over the medium-term	Electricity	Netherlands	Private homes	1. Energy consumption 2. Comparison with personal saving targets	*Detail not available	10 seconds	Real time	26	11 months	1. Display 2. Website	Longitudinal	7.8

12	Gleerup, 2010	The effect of feedback by text message (SMS) and email on household electricity consumption: Experimental evidence	Electricity	Denmark	1. Detached houses 2. Terrace/ town house	1. Energy Consumption 2. Comparison with historical consumption	1. Numeric 2. Text 3. Graph	*Detail not available	Group 1: Weekly Group 2 & 3: Daily/ Weekly/ Monthly	1452	12 months	1. Email 2. SMS	Randomized Control Trial	3
13	Allcott, 2011	Social norms and energy conservation	Electricity	US (covering 24 states)	*Detail not available	1. Past energy consumption 2. Comparison with neighbors 3. Tips	1. Numeric 2. Text 3. Graph	Once in 1/2 months (Manually)	Monthly/ bimonthly or quarterly (depending on the utility)	600000	2 years*	Letters (Home Energy Report)	Longitudinal	2
14	Schleich, 2012	Effects of feedback on residential electricity demand-findings from a field trial in Austria	Electricity	Linz, Austria	*Detail not available	*Detail not available	*Detail not available	Hourly	Web portal: Daily Post mail: Monthly	1525	12 months	1. Web portal 2. Post mails	Randomized Control Trial	4.5
15	Marchiori, 2012	Building the case for automated building energy management	Electricity	Canada	*Detail not available	1. Energy consumption 2. Tips (Non IHD group)	1. Numeric 2. Text 3. Graph	5 seconds	Real time	10	10 weeks	IHD (on a laptop computer)	Longitudinal	20
16	Vassileva, 2012	The impact of consumers' feedback preferences on domestic electricity consumption	Electricity	Sweden	Apartment and private houses	1. Energy consumption 2. Comparison with historical data 3. Energy cost 4. Outside temperature 5. Tips 6. Comparison with similar households	1. Numeric 2. Graphic	*Detail not available	Daily	1104	3 years	1. Display (attached with energy meter) 2. Web page (EnergiKollen)	Longitudinal	15
17	Houde, 2013	Real-time Feedback and Electricity Consumption: A Field Experiment Assessing the Potential for Savings and Persistence	Electricity	US	Single family detached households	1. Total consumption 2. Cost 3. Past comparison 4. Budget tracker 5. Projected consumption 6. Tips 7. Email Reminders	*Detail not available	10 minutes	Real time	1065	Phase 1: 3 months Phase 2: 6 months (called after experiment)	1. Web interface 2. Email reminders	Randomized Control Trial	5.7

18	Vassileva, I.,2013	Energy consumption feedback devices' impact evaluation on domestic energy use	Electricity	Sweden	Apartments	1. Hot water consumption 2. Comparison with neighbors 3. Comparison with historical data 4. Electricity consumption Group 2: 5. Appliance wise consumption 6. Standby consumption	1. Numeric 2. Text 3. Graph 4. Chart	Daily	Weekly	80	1 year*	1. IHD; SMS; letter 2. Common display 3. IHD 4. TV-channel	Longitudinal	10
19	James, 2013	Reducing Electricity Demand through Smart Metering: The Role of Improved Household Knowledge	Electricity	Ireland	*Detail not available	Energy usage statement: 1. Electricity consumption 2. Comparison with historical data 3. Comparison with other customers 4. Advice/ tips IHD 5. Cost and tariff 6. Daily budget	*Detail not available	*Detail not available	Energy usage statement: Bi-monthly IHD: Real time	5000	12 months	1. Energy usage statement 2. IHD	Randomized Control Trial	1.9
20	Young., 2013	Variations on the normative feedback model for energy efficient behavior in the context of military family housing	Electricity, Gas	Maryland, US	1. Townhouse 2. Duplex 3. Single Family	1. Energy consumption 2. Efficient neighbors' consumption 3. All neighbor's consumption 4. How you're doing (Great/ good/ more than average) 5. Tips	1. Numeric 2. Text 3. Graph	1425 observati ons collected in 3 months	Monthly	475	3 months	Home energy reports (as utility billing process)	Randomized Control Trial	4.9
21	Shimada, 2014	An Empirical Study of Electric Power Demand Control by RealTime Feedback of Consumption Levels: Case of Nushima Island households	Electricity	Nushima Island, Japan	*Detail not available	1. Electricity consumption 2. Comparison with neighbors 3. Ranking with participating homes	1. Numeric 2. Graph	*Detail not available	Real time	51	Pattern 1: 4 months Pattern 2: 2 months Pattern 3: 2 months	Tablet PC	Longitudinal	7.6

22	D'Oca, 2014	Smart meters and energy savings in Italy: Determining the effectiveness of persuasive communication in dwellings	Electricity	Italy	*Detail not available	1. Energy consumption 2. Comparison with historical data 3. Comparison with similar households Newsletter 4. Standby energy consumption 5. Suggestions	1. Numeric 2. Graphic	2 minutes	Real time	12	13 months*	1. Web based 2. Newsletter (via email)	Longitudinal	18
23	Schultz, P. W., 2015	Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms	Electricity	Southern California	Single family households	1. Energy consumption 2. Equivalent cost 3. Comparison with neighbors 4. Change in LED colour based on consumption	1. Numeric	5 seconds	Real time	431	3 months	IHD	Randomized Control Trial	7
24	Xu, 2015	Case Study of Smart Meter and In-home Display for Residential Behavior Change in Shanghai, China	Electricity	Shanghai, China	New built apartments	1. Energy bills 2. Local energy utilization 3. History electricity data 4. Energy saving suggestions	1. Numeric 2. Text 3. Graphs*	15 minutes	*Detail not available	131	1 month*	IHD	Randomized Control Trial	9.1
25	Stinson, 2015	Visualizing energy use for smart homes and informed users	Electricity, Gas	Scotland, UK	Group A: Flats Group B: Semi Detached houses	1. Weekly energy consumption 2. Peak energy use 3. Equivalent cost 4. CO2 levels	1. Numeric 2. Graph	2 Seconds	Real time	52	6 months	IHD	Randomized Control Trial	20 7
26	Podgornik, 2016	Effects of customized consumption feedback on energy efficient behavior in low-income households	Electricity	Mediterranean area 1. Spain 2. France 3. Malta 4. Cyprus	72% apartment in multiple dwelling building	1. Electricity consumption 2. Appliance wise consumption 3. Energy efficiency 4. Energy costs 5. Tips 6. Benchmark with neighbors 7. Annual CO2 emission	1. Numeric 2. Text 3. Graphs 4. Charts	*Detail not available	Real time	Case 1: 100 Case 2: 25	2 years*	IHD	Longitudinal	36.4
27	Mogles, N., 2017	How smart do smart meters need to be?	Electricity, Gas	UK	Social housing	1. Energy consumption 2. Equivalent cost 3. Tailored action prompts	1. Numeric 2. Text	5 minutes	Real time	43	3 months	IHD	Longitudinal	22

28	Kendel, 2017	What do people ‘learn by looking’ at direct feedback on their energy consumption? Results of a field study in Southern France	Electricity	Southern France	*Detail not available	1. Energy consumption	1. Numeric 2. Graphs	2 minutes	Real time	65	8 months (collecting phase)	Interactive ICT (information terminal)	Longitudinal	23.3
29	Nilsson, 2018	Effects of continuous feedback on households’ electricity consumption: Potentials and barriers	Electricity	Sweden	Study 1: Separate or semi detached houses Study 2: Rented apartments	1. Electricity consumption 2. Equivalent cost 3. CO2 emission	1. Numeric 2. Text 3. Graph	*Detail not available	Real time	154	1 year	1. IHD (TIngco Homes) 2. Mobile App	Longitudinal	9.5
30	Romano, 2019	Experimental demonstration of a smart homes network in Rome	Electricity	Centocelle, Rome	1. Flat in multi-family and two-family apartment block 2. Detached house	1. Daily energy consumption 2. Equivalent cost 3. Comparison with previous year 4. Appliance wise consumption 5. Weather conditions (indoor/ outdoor) 6. Comments	1. Numeric 2. Text 3. Graphs 4. Charts	*Detail not available	Real time	10	*Detail not available	Web App (accessible from computer/ mobile phone)	Longitudinal	10
31	Canale, 2021	Do In-Home Displays affect end-user consumptions? A mixed method analysis of electricity, heating and water use in Danish apartments	Electricity, heating, water	Denmark	Apartments	1. Total consumption 2. Cost 3. Goal and Tips	1. Text 2. Pictures	*Detail not available	*Detail not available	244	3 years*	IHD	Longitudinal	Cold water: 17 Hot Water: 23 Electricity: 12 Heating: 17
32	Marangoni, 2021	Real-time feedback on electricity consumption: evidence from a field experiment in Italy	Electricity	Italy	*Detail not available	"1. Current power usage 2. Billing time slot 3. Historical consumption 4. User defined consumption threshold"	"1. Numeric 2. Graph"	*Detail not available	Real time	*Detail not available	*Detail not available	IHD	Longitudinal	1.9
33	Trinh, 2021	Effects of Real-Time Energy Feedback and Normative Comparisons: Results from a Multi-Year Field Study in a Multi-Unit Residential Building	Electricity	Canada	Rental Multi Unit Residential Building	"1. Current consumption 2. Goal Setting 3. Historic comparison 4. Normative comparison"	"1. Numeric 2. Text 3. Graph"	*Detail not available	Real time	24	1 Year	IHD (provided android tablet)	Longitudinal	12.8

3.3 Proposed taxonomy for feedback characteristics

Research on feedback related to residential electricity consumption shows that feedback can promote change in behavior and reduce consumption (Schultz, 2015). Several researchers have used different criteria to build feedback typologies and increase energy consumption awareness.

(Darby, 2001) showed feedback in terms of immediacy and control on two axes, approximately related to the level of immediacy and the extent to which the energy user is in control of finding and using the information. The author classified feedback as 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). The direct and indirect classification was also mentioned in (Darby, 2006), (Neenan, 2009), (Kerr, 2012), (McKerracher, 2013), (Zvingilaite, 2015), (Serrenho, 2015) and (Zangheri, 2019). (Abrahamse, 2005) discussed studies based on periodicity of the feedback: continuous, daily, weekly, monthly, feedback with comparison, and feedback with monetary rewards. (Fischer, 2008) classified the types of feedback based on its characteristics such as frequency (example real time, monthly, daily) and content (energy units (kWh), cost, comparison of consumption with neighbors) provided in the feedback, breakdown (appliance wise, room wise), presentation (the way it was communicated visually)and inclusion of comparisons (either with historic data or with peers/neighbors). (Zangheri, 2019) also proposed a classification based on the type of information that can be provided. (Neenan, 2009) distinguished feedback based on standard billings (typical utility bills), enhanced billings (comparison with past data or with neighboring consumption), estimated feedback (projected consumption), periodicity (daily, monthly), real-time and real-time plus (including appliance-wise disaggregation). (Froehlich, 2010) proposed 10 design dimensions to classify feedback: frequency, measurement unit, data granularity (e.g., do users see data from each appliance or the whole house), accessibility (e.g., push vs. pull), presentation medium, location, visual design, recommended action, comparison, sharing via social media. (Serrenho, 2015) proposed one way and two-way communication with the grid in the classification. One way communication with the grid involved receiving actionable tips from the grid and two-way communication allowed users to give feedback on the information received from the grid. (Karlin, 2011), (Karlin, 2014) reviewed the feedback classification provided by different researchers like (Darby, 2001), (Darby, 2006), (Neenan, 2009), (Ehrhardt, 2010) and (Pritoni, 2012) and mentioned the gaps in them. Further (Karlin, 2014) suggested that categories within a classification should be clearly defined, mutually exclusive (one thing should not fall in two categories), and collectively exhaustive (it should cover everything).

There have been several attempts to classify the feedback characteristics. However, there has been no commonly accepted classification. Our work reviews the insights of different authors and publications on field studies to derive a valid feedback characteristic taxonomy following the 3 criteria suggested by (Karlin,2014). Figure 3.1 shows the taxonomy derived by us for characteristics of energy feedback.

The characteristics of feedback are classified as:

- Transmission medium - Transmission refers to the way information is broadcast. In energy feedback literature, two mediums of transmission are used, digital (online) and printed (offline).

- Frequency - Frequency of any event can be defined as the number of times the given observation occurred/ was recorded. Here frequency refers to the data sampling frequency and feedback frequency.
- Access - Access is defined as the way feedback information is made available to the residents. Access is further classified as type (direct and indirect) and connection initiation (push and pull).
- Information - Information is the key element of energy feedback. It is something that is finally going to reach the energy consumer. Information is of five types: simple, conjunctive, tips, and advice, forecast, demand response, and statistics.
- Presentation - Presentation encompasses the manner or style in which something is displayed. The mode of presentation may be static (infographic, text, image) or dynamic (animation, audio, or video).
- User Engagement - User engagement measures whether customers find a product or service valuable. Engagement can be measured by a variety or combination of activities such as taps on the screen or time spent on the screen (active time on the app screen).

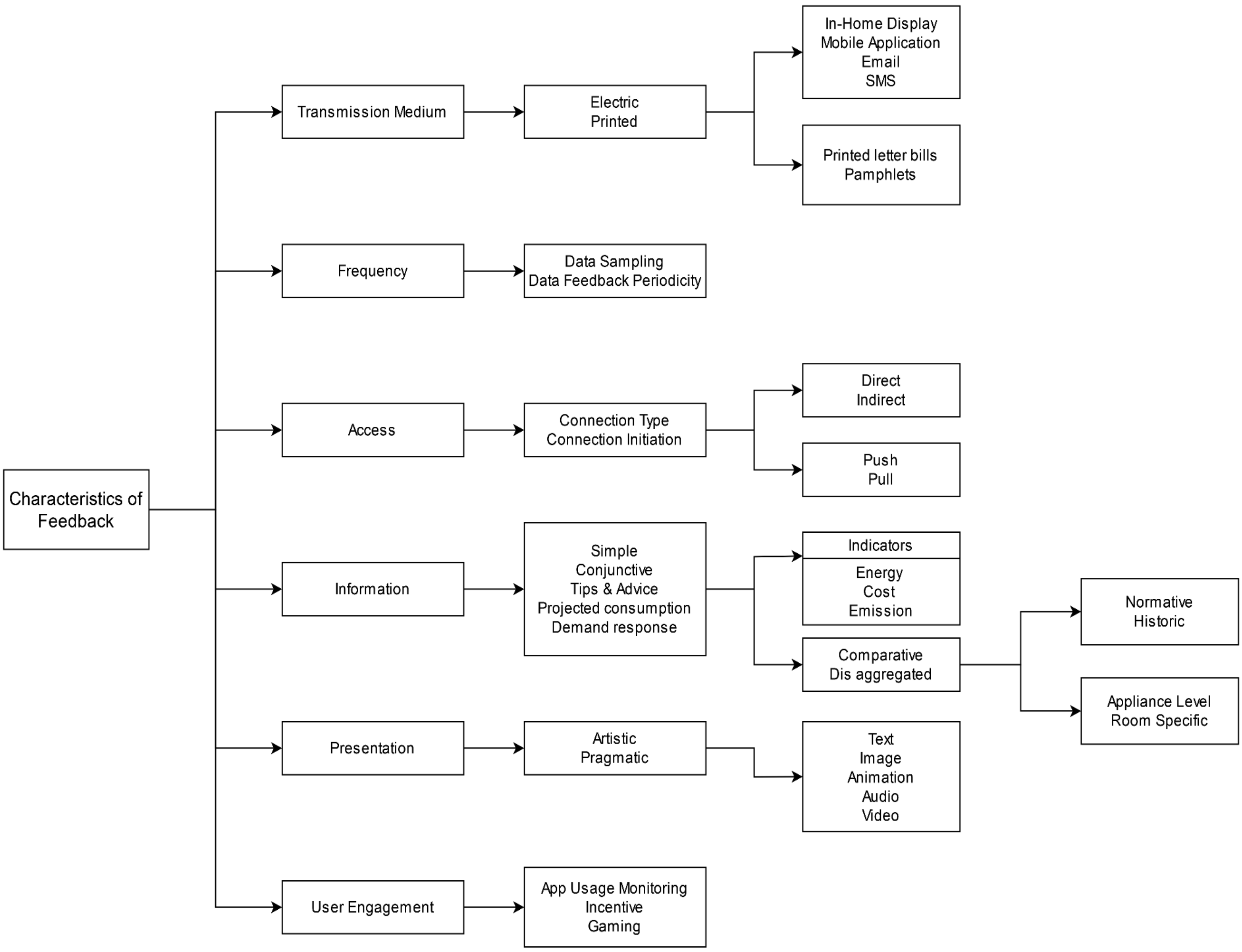

Figure 3.1. Characteristics of energy feedback

Based on Figure 3.1 we show various types of feedback that are used in the field trials of the reviewed publications. The following subsections explain each of these categories.

- **Transmission Medium**

Transmission refers to the way information is broadcast. In energy feedback research, medium refers to the method of communicating feedback information to the user. The two transmission mediums used in literature are digital/electronic and printed. This terminology is easy to understand and is widely accepted in literature (Fischer, 2008), (Froehlich, 2009), (Froehlich, 2010), (Schleich, 2013). Feedback via electronic medium includes communication through IHD, web app, mobile app, email, and SMS. Electronic feedback such as SMS and email are low cost and easy to implement as compared to print medium. Printed feedback can be given via simple/detailed printed energy bills, printed letters, or pamphlets.

- **Frequency**

Frequency of an event is defined as the number of times an observation has occurred/ was recorded (Field, 2013). In energy feedback literature, frequency is often used interchangeably with the terms data sampling frequency and feedback frequency. Sampling frequency focuses on precision of data recording i.e., recording energy data using smart meters and appliance monitors at varied units of time such as seconds, minutes or months. . Feedback frequency on the other hand focuses on the interval between consecutive feedback provided to the consumer. It becomes challenging for the energy feedback designer to estimate the user-based optimal frequency for sharing feedback. The designer needs to strike a balance between acquiring information from the customer and the customer's emotional response (interaction with interface)such as annoyance or pleasure. Usually, the more often the feedback is given, the more significant is the contribution to changing user behavior (Ueno, 2006), (Roberts, 2003). It is important to let the user choose the desired frequency of feedback on their device (Darby, 2006).

Additionally, feedback resolution is a critical aspect of feedback frequency. It gives the time period for which a user intends the data to be updated on the feedback medium. Feedback resolution may be daily, weekly, monthly, or real-time. For example: a user might want to get a monthly bill for overall energy consumption (daily feedback frequency) on the and in that getting weekly/daily data is feedback resolution.

The ideal frequency for feedback is unknown as it may vary based on consumer preference, capability of the feedback system and the type of intervention planned in the program (Kerr, 2012). (Allcott, 2011) found that even though monthly reports may lead to higher savings, quarterly reports can also be cost effective. Thus, real time feedback improves chances of occupants taking immediate action on their energy consumption while delayed feedback helps them understand their consumption patterns and realize what they can do to save more energy in the long run.

- **Access**

We define access as the way feedback information is made available to the residents. Access can be further classified as type (direct and indirect) and connection initiation (push and pull).

A widely used classification by (Darby, 2006) is the direct and indirect feedback. The author states that when the user is presented with raw information that is recorded on the energy meter or an associated display monitor, then it is called direct feedback. Direct feedback is the immediate and easily accessible consumption feedback such as an in-house display monitor or a clearly visible energy meter (Zvingilaite, 2015). In indirect feedback, data is processed before providing it to the user, usually through energy bills (Darby, 2006). The data processing in indirect feedback causes delays in providing feedback by a day (e.g., if meters are read each night) or longer (Zvingilaite, 2015). Direct or indirect feedback, both are different concepts and demand different attention. On one hand, the accessibility of direct or indirect information facilitates user control (Nilsson, 2014), in which the user can benefit from the comprehensive representation of the energy feedback because of post-processing (for e.g., infographics), on the other hand how much time it takes to present the data could be addressed as latency in presenting the feedback. The latency in accessing the feedback (i.e., Real Time or delayed) is discussed in frequency (feedback frequency) and direct-indirect feedback is used to describe the level of processing the data has undergone before reaching the user.

Access to data can also be looked at from the point of view of who initiates the data sharing. Pull type feedback is when the user asks for the feedback. The request can be initiated by different means such as clicking a button on a feedback application (in a smartphone) and based on the parameters selected by the user, information/feedback can be made available by the service provider. Push type feedback can be sent by the service provider, it may be periodic, or trigger based (for example raises an alarm or indicator when consumption reaches a threshold). Push/Pull type feedback has been discussed by (Kerr, 2012), where the authors suggest that to achieve energy saving, a balance of push notification needs to be maintained so that the user is not overwhelmed by the feedback provided.

- **Information**

Information is the key element of energy feedback. It is something that is finally going to reach the energy consumer. Information can be of five types namely - simple, conjunctive, tips /advice, projected consumption, and demand response.

a. Simple

Simple information is the basic information provided to consumers about their energy consumption. This is done by providing consumed energy as per appropriate energy units or performance indicator used. Performance Indicator refers to the single or multiple data points that present essential information, such as energy units (kWh), energy cost (₹) and carbon emission (Kg of CO_2). Information presented through performance indicators are easy to understand and communicate but it might not be sufficient for taking energy conservation steps and might not give detailed information like appliance level feedback, comparison with households having similar consumption.

b. Conjunctive Information

Conjunctive information refers to the context in which the energy feedback information is provided. It offers a relational perspective in presenting information. The current work classifies the conjunctive information into comparative and disaggregated energy consumption. Comparative information refers to comparison of energy consumption with users' historic parameters or with their neighbors and/or peers. Disaggregation is the comparison of energy consumption at the appliance or room level. Such information helps users understand the contribution of individual components to energy consumption.

c. Tips and Advice

Tips and advice are simple text messages which help the user understand actions that can be taken to save energy. Tips may be generalized or personalized. (Matsui, 2014) provided fixed generalized saving tips such as “keep air filter clean”, which are not based on energy monitoring and can become monotonous and non-effective after some time. (Ueno, 2006) provided actionable tips such as "You used TV, 5 hours on 12 Jan 2002. Standby power was consumed at other times which were designed based on consumption of the household. Turn off the switch when not in use." Generating such tips can be more engaging for users as the tips change according to the energy consumption, and this might encourage users to save more.

d. Projected Consumption

Projected consumption refers to the estimated projection based on the users’ historic consumption patterns. These forecasts may pertain to users’ energy consumption, its derived costs, or emissions. Adding forecasts in the feedback helps the users understand how much energy they might be consuming the next day or by the end of month. The only issue in providing such predictions is that the data needs to be enough to significantly predict the consumption for the upcoming day, week, or month. Thus, a good energy consumption baseline is a must for giving predictive information in the feedback.

e. Demand response

Demand response enables consumers to play an important role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to time-based rates or other forms of financial incentives. To engage consumers in demand response, consumers are offered time-based rates such as time-of-use pricing, critical peak pricing, variable peak pricing, real time pricing, and critical peak rebates. It also includes direct load control programs where power companies can cycle air conditioners and water heaters on and off during periods of peak demand in exchange for a financial incentive and lower electric bills. Demand response is a valuable resource and its capabilities and potential impacts have become multifold by grid modernization efforts. For example, sensors can perceive peak load complications and utilize automatic switching to divert or reduce power in strategic places, which eliminates the chance of overload and the resulting power failure.

- **Presentation**

Presentation encompasses the manner or style in which something is displayed. The mode of presentation may be static (infographic, text, image) or dynamic (animation, audio, or video).

Presentation (Fischer, 2008), visual design (Froehlich, 2009), and display design (Kerr, 2012) are terms used by different authors to address one of the important aspects of feedback which is communication. (Pierce, 2008) used the term “data visualization” in the context of energy feedback and adopted the classification by (Kosara, 2007) where visualization was categorized into two general types: pragmatic visualization and artistic visualizations. (Kosara, 2007) terms ‘pragmatic visualization’ as a representation of information with minimum manipulation in contrast to “artistic visualization” where different visualization techniques are used to express a point of view. Pragmatic visualizations aim to provide factual data or analysis (Westcott, 2020). Artistic visualizations abstract the data to display it in a more sublime and easier to understand at-a-glance way, in addition, the aesthetically pleasing presentation is intended to encourage user engagement with their energy consumption (Westcott, 2020).

- **User Engagement**

User engagement measures whether users find product or service valuable in this scenario lead to considerable savings in energy consumption resulting from effective user engagement. Engagement can be measured by a variety or combination of activities such as clicks, time spent on the screen and more. User engagement is assessed through monitoring app usage, and can be enhanced through incentive or penalty, and gaming.

To understand the interaction between the user and the feedback interface, user activity on the interface can be monitored. Activity monitoring can track how much time a user has spent on the interface, what information and mode of presentations were chosen by the users and what actions were taken. This can help in developing dynamic feedback which can change based on user behavior, preferences, and the actions they take.

3.4 Results and discussion

In the feedback characterization section it is noticed that for the same type of feedback, energy savings can vary depending on the way a study is conducted i.e., demographics, building orientation, size, duration, and the way savings are calculated (Randomized Control Trial, Longitudinal studies).

The size of the study sample should be considered when analyzing and evaluating the representativeness of the results (Chiang, 2012; Fischer, 2008). Most studies do not investigate details regarding the size of the sample (Chiang, 2014; Darby, 2001; Ehrhardt, 2010; McKerracher, 2013). (Ehrhardt, 2010) concluded that large samples (more than 100 households) have a lower average reduction in consumption (6.6%) when compared to the small sample studies (11.6%). For example, (Ueno, 2006), analyzed savings of only nine households, found satisfactory (9%) savings. (James, 2013) analyzed five thousand households, found very low (2%) savings. (Darby, 2010) evaluated six studies with large samples, found an average reduction of 4% only.

Duration of the study can be short (up to four months), medium (four to fifteen months) and long(more than fifteen months) (Van, 2010). Most studies (eg, Alahmad, 2002; Xu, 2015; Marchiori, 2012; Ueno, 2006) are short-term and manage to achieve consumption reductions upto 20%. (Darby, 2006) states that the longer the period in which the feedback is provided, the more effective the reduction in energy consumption will be. This is because the user is able to formulate new habits to achieve greater consumption reductions. However, the study by (Van, 2010) analyzed the effects of feedback in the long term and found that users do not maintain reductions in consumption (the 7.8% reduction from the first four months was not sustained after 11 months). (Ehrhardt, 2010), when reviewing 48 studies, also identified that short-term studies have higher average energy savings (10.1%), unlike longer studies (7.7%).

The Hawthorne effect is a factor that can also influence the greatest reduction in consumption in short-term studies (Wilhite, 1995). This effect happens when participants change their behavior if they know they are participating in an experiment and that they are being observed (Wood, 2003). (Ehrhardt, 2010) states that, for short-term studies, the Hawthorne effect can contribute to the reductions being even greater unlike the long-term studies, in which the participants get used to the idea of the experiment and they even forget that they are participating.

We attempted to understand the different ways in which studies are conducted and assess a few parameters to establish their relationship with the energy savings achieved. Among the field studies reviewed, it has been observed that generally, the studies report energy savings as percentage savings achieved. Savings in some studies are reported in kWh, cost, or CO_2 emissions. The following discusses the study parameters that show a significant relationship with energy savings.

- **Savings - Depending on the Fuel Type**

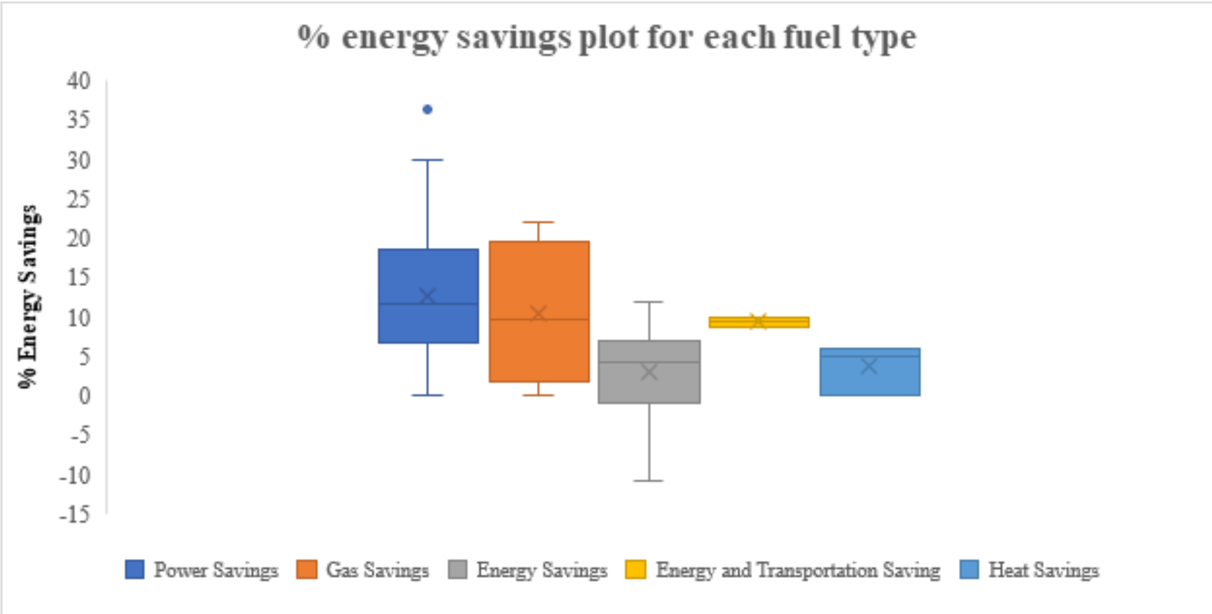

Figure 3.2. Percentage energy savings achieved for different fuel types along with number of interventions.

Field studies in Figure 3.2 show that savings were reported for different fuel types and combination of fuel types such as electricity or power, gas, combined savings in gas and electricity, energy savings (both electricity and gas) along with saving in transportation fuel and saving in heating energy (for e.g., mean specific heat). It is observed that most of the intervention studies have reported electricity or power savings. It is interesting to note that there are studies which have shown the impact of feedback on conservation of transportation fuel along with savings in electricity and gas. During the review it was found that each study has sub-studies for example in one study there may be two groups having different intervention, one might assess impact of feedback on power or electricity savings and the other assess gas savings. The numbers indicated in the above graph show the number of interventions that are carried out in 33 studies that are reviewed in this paper. Most studies conducted feedback interventions aiming to reduce electricity consumption.

- **Savings - Depending on the Experiment Type**

Studies conducted experiments while comparing the energy consumed by a group of users to the energy consumed in a particular time period. The studies are termed Randomized Control Trial (RCT) and longitudinal studies. In the case of calculating energy savings in longitudinal studies if the baseline time period is not in the same season as the experiment period, there is a possibility for inherent change in consumption due to seasonal change irrespective of the feedback intervention made. Due to irregularities in measuring seasonal impacts, chances are that longitudinal studies tend to show a higher range of energy savings in comparison to Randomized Control Trial studies. It can also be seen that some studies have compensated for these changes using statistical methods. The studies which compare energy savings achieved among two groups of users who have similar energy consumption patterns are referred to as Randomized Control Trial studies. RCT studies as represented in Figure 3.3 show savings ranging from 0-24 %, whereas longitudinal studies show savings ranging from -10 to 30 %. The negative savings here represent an increase in energy consumption. Also, as represented by the range of savings RCT studies comparatively show lesser savings and longitudinal studies are bound to show higher range of savings due to various reasons mentioned above.

Figure 3.3. Percentage energy savings for different Experiment types.

- **Savings - Depending on the Duration of Study**

Duration of a study is considered as the period of study for which the energy savings are reported. Duration is one of the parameters that influence the energy savings achieved. There are two effects that lead to energy savings – the first being behavioral change of users because of the feedback intervention made and the second being change of household appliance to an energy efficient appliance. It is often seen that the energy savings caused due to behavioral change are seen to reduce with time. This is due to the reduction in novelty of the intervention made. It is also observed that users have removed the IHDs providing feedback, this may be due to loss of interest in participating in energy saving activities.

In Randomized Control Trial studies, as seen in Figure 3.4, energy savings are seen to reduce with time. This may be due to loss of novelty with time. Studies with shorter duration show better savings due to constant engagement with the users in the intervention period. It may also be that there is no learning taking place, or the intervention is not being translated to real time learning.

As seen in Figure 3.5 energy savings in longitudinal studies increases with duration of study which is completely opposite from the relationship between duration and energy savings in Randomized Control Trials. One of the reasons for this may be the comparison of savings across different seasons leading to energy savings being calculated using an inaccurate method and being reflected as high savings.

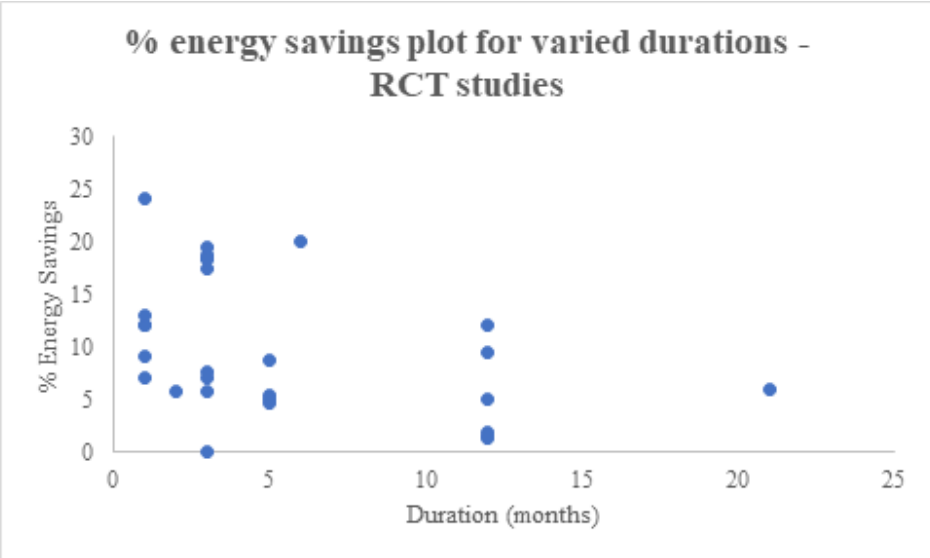

Figure 3.4. Percentage energy savings for RCT studies with varied durations

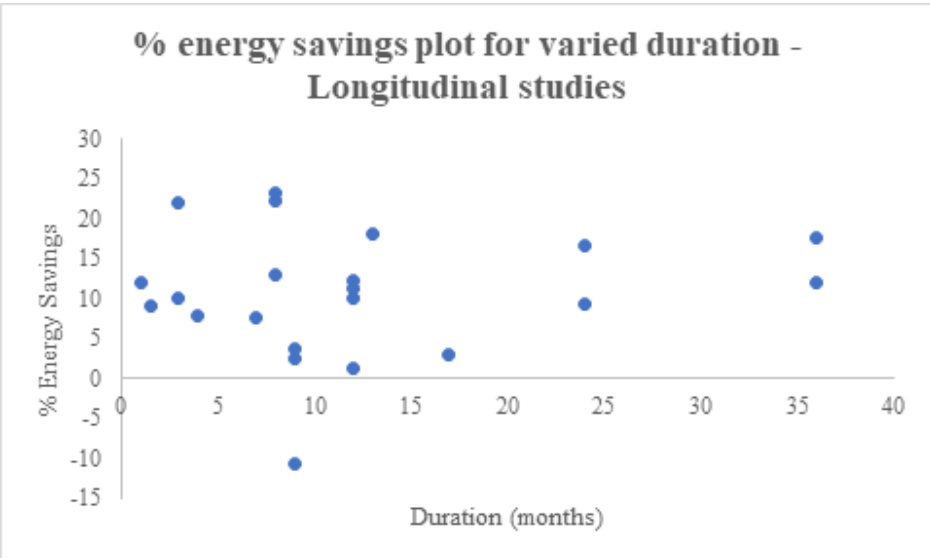

Figure 3.5. Percentage energy savings plot for varied duration of Longitudinal studies

- **Savings - Depending on the Experiment Size**

As seen in Figure 3.6 and 3.7, bigger studies show lesser saving because involvement with participants is low in bigger studies and higher in smaller studies. This relationship is similar in both longitudinal and Randomized Control Trials. The consistent engagement with the participants may have led to their lasting interest in the study resulting in higher savings.

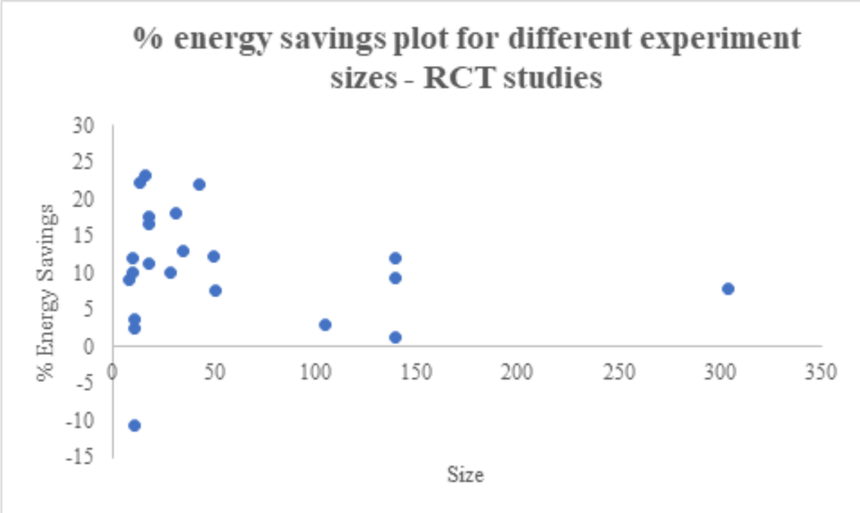

Figure 3.6. Percentage energy savings for different experiment sizes of RCT studies

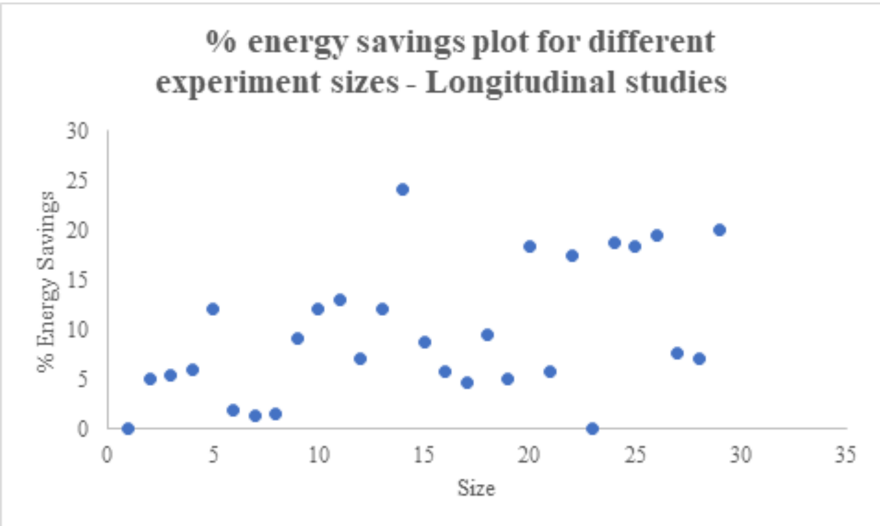

Figure 3.7. Percentage energy savings for different experiment sizes of Longitudinal studies

Apart from energy savings from feedback, demand response is also gaining popularity with the need for the energy providers to meet the intermittent nature of renewable energy sources whose share is increasing in the energy generation mix. This makes it important that feedback provided for demand response is effective enough to involve the consumer. Although it's impact evaluation is not straightforward and involves complex methodology (Valentini, 2022)

It is also important to understand the fall-back behavior or rebound effect in which energy reductions due to energy efficiency is compensated by increase in energy due to behavioral changes. Rebound effect occurs when a home inhabitant uses a new appliance much more than the older one, due to its higher efficiency (Bertoldi, 2022). The result would be no change, or worse, an increase in energy usage. However, because of the rebound effect a change in behavior can't be necessarily related to change in energy consumption (Wilson, 2015). (Bertoldi, 2022) also talked on rebound effect as the main reason for the failure of traditional feedback.

It is challenging to decide which information is most effective and helps achieve best results for saving energy. To determine the effectiveness of feedback information, we think there is a need for studies which compare different feedback information, especially considering its impact over a longer period. We believe there are two ways to achieve significant energy savings.

- by making people more aware of their energy consumption along with energy feedback information.
- by taking measures that enable inculcating energy saving practices as a habit and quantifying the impact of the action performed (giving users an understanding of the actual amount of energy saved).

There is a need to design and implement studies which are large scale – representing overall population, over a longer duration, while comparing control group and intervention groups where one intervention group is provided energy feedback and another group is provided energy feedback along with automation to understand if automation combined with feedback is a successful intervention and successfully results in sustained energy savings. Also, most of the reviewed studies are in developed countries and cold climate regions. There is a need for studies in tropical regions and developed countries, especially because of increasing cooling demand in these regions. To address the rebound effect, implementing automation at the household level can help mitigate the monotony of customer responses to energy feedback and reduce the need for frequent engagement at various levels.

Effective feedback results from a valid combination of parameters discussed in the characteristics of feedback section. A feedback device should not necessarily present all the data available about energy consumption. It is important for the feedback system to investigate what types of information should be presented to users so that they can learn from their consumption and be able to reduce it. Conducting a survey among the focus group to understand the user preferences on the type of energy feedback information before actual implementation of the feedback system can help in designing an effective feedback. Savings from energy feedback depends on how efficiently it provides important information to the user and how easily the user is able to take actions on them. For users to be interested in feedback, they should be provided with information as per their preferences (Bertoldi, 2020).

3.5 Conclusion

This chapter provided us insights on how important feedback is to achieve savings from residential energy consumption. Motivated by the findings from this chapter, we used the methodology mentioned in the next chapter to systematically conduct our research on the design of User Interface for Energy Feedback.

Chapter 4

Research method for interface design

4.1 Design Science Research

The research method used in this study is **design science research**, also titled as constructive research or prescriptive research. This method is a process of (i) proposing artifacts/solutions to solve problems in a systematic way, (ii) evaluating what was designed or what is working, and (iii) communicating the results and contributions obtained (Holmstrom, 2009). In this method, the researcher plays the role of a problem-solver, in which he explores new alternatives and their developments (Holmstrom, 2009). Its main objective is to develop knowledge for the elaboration and creation of artifacts/solutions to relevant problems, considering the context in which they will be applied (through systematic literature review, exploratory studies, etc.) (Aken, 2004). So, with the design science, a solution/artifact is proposed and not just applied to an existing one. This type of research helps in solving real problems, generating knowledge that can be generalized to other situations (Aken, 2004). Generalization allows other researchers to also use the knowledge generated (Aken, 2004). The design science research seeks to reduce the gap between theory and practice, but maintain the necessary rigor that ensures the reliability of the research results.

The design science research approach has been compared in several studies with: (i) formal sciences (philosophy and mathematics); (ii) explanatory sciences, such as natural sciences (physics, chemistry and biology) and social sciences; (iii) positivists; and (iv) interpretive (eg: March, 1995; Aken, 2004). Furthermore, descriptive research focuses on the problem, while prescriptive research focuses on the solution (Aken, 2004). In this method, the researcher develops an artifact/solution to solve the problem (Holmstrom, 2009).

(March, 1995) introduced a framework consisting of four distinct types of artifacts or solutions. The first type is "constructs," which refer to conceptual ideas or concepts used to describe a problem. These constructs serve as the building blocks for understanding and addressing the problem at hand. The second type is "models," which are sets of arguments or representations that illustrate the relationships between the constructs. Models help in visualizing the connections and dependencies between different elements within the problem domain. The third type is "methods," which encompass a set of steps or procedures designed to perform specific tasks or activities. Methods provide guidance on how to tackle the problem systematically and achieve desired outcomes. The fourth type is "implementations," which involve the operationalization of constructs, models, and methods. Implementations bring the theoretical concepts and frameworks into practical existence by putting them into action. Later, (Aken, 2004) proposed a fifth type of artifact/solution: theories based on design science. These theories incorporate the principles and insights derived from the previous four types of artifacts. They provide a deeper understanding of the problem domain and contribute to the development of design-oriented knowledge.

Thus, the expanded framework includes constructs, models, methods, implementations, and theories based on design science as five distinct types of artifacts or solutions. Each type plays a crucial role in addressing problems, fostering innovation, and advancing knowledge in the field of design science.

This research was designed as per the following steps of design science research method proposed by (Lukka, 2003):

- find practical and relevant real-world problems that cause theoretical contributions and involve theoretical and practical research
- gain a deep understanding of the problem
- propose an innovative solution that solves the problem (performed through empirical cases based on the literature review)
- implement the solution and assess whether it works
- identify and analyze practical and theoretical contributions.

Our research problem is related to the lack of guidelines for the design of feedback interfaces for displaying energy consumption in homes. The artifact will be a set of guidelines for designing feedback interfaces differentiated by types of users. The secondary artifact will be conceptual models of feedback interface based on the guidelines. The research contributions are related to advances in the analysis of the content and design of user interface through the identification of preference for feedback of different types of users.

The steps of design science research were separated as follows:
Step 1 involved finding and understanding the problem. An initial exploratory search took place to evaluate the impact of energy feedback on residential energy consumption. A thorough understanding of the problem occurred through a systematic literature review to identify what types of information are presented in the feedback interfaces and in what format.
Step 2 addresses the development of empirical cases, through questionnaires for data collection with focus groups. The questionnaires were gradually refined according to pilots and, when completed, their application was carried out with two types of users (young adults and middle aged adult citizens) to present the data analysis.
Step 3 involved designing the User Interface Screens for the feedback. These designs were based on the thorough literature review done and the significant results of the survey conducted.
Step 4 validation of the analyzed results by verifying with the participants about their preferred complete screen designs. Another survey was conducted for the same in the same focus group.
Step 5 covers the proposal of guidelines and conceptual models for the design of visual interfaces. Finally, the theoretical contributions of the research were identified.

4.2 Questionnaire for 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:

- Study Instructions: This section included a welcome note, a consent form, and basic information about the research.
- Demographic Details: This section included questions to obtain demographic information such as gender, age, education level, income, and occupation.
- Energy Literacy: This section included questions to assess the user's level of knowledge about energy consumption.
- 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.
- Electricity Feedback Interface: This section included general information about the feedback interface, along with an example of how a feedback interface looks like.
- 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/₹.
- 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.
- 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.
- Thank You Note: This section included a thank you message to the user for their participation in the survey.

The questionnaire was constructed using the information elements identified in the literature. Information elements were presented in the questionnaire to gain insight into how well participants understand and prefer the formats and types of information through their choices and opinions. The information formats were carefully designed to be simple and use the same types of graphic design to make them comparable to each other. By organizing the questionnaire in this manner, we aimed to obtain comprehensive data on user preferences for energy consumption feedback.

4.3 Refining of the questionnaire

The application of pilot questionnaires with young adults and middle-aged people allowed it to be revised to suit the need and understanding of the participants. First, it was necessary to include in the introduction an explanation of what visual interfaces are and their examples, since these interfaces are not widely known in India. Further, questions demanding text based responses from the user were removed or changed to multiple option type questions. This was done to make responses more organized for the analysis and is also convenient for users to answer.

4.4 Data collection

Data collection was performed with two focus groups of participants from two age groups (young adults and middle aged adult citizens). Young adults' age range was from 18 to 24 years and middle aged adults' age range was from 25 to 45 years. A total of 446 participants (190 adults and 256 elderly citizens) participated in the survey. This method was chosen for data collection because several previous studies used it similarly (eg Anderson, 2009; Karjalainen, 2011) (Petersen, 2007; Roberts, 2004; Wilson, 2015).

The data was collected by sending the online survey link to the participants interested in the study. The survey required roughly 10-20 minutes of participants time to complete the survey. The online survey was circulated using emails and social media groups. The target audience were students and parents from the IIIT community. To reach more people and bring diversity in responses, people in the IIIT community were asked to share the google form link for the survey in their friends and friends of friends groups. User consent was taken before starting the questionnaire, consent form attached in Appendix B. Ethics approval was also taken from the ethics committee of the college. Ethics approval form attached in Appendix C.

Chapter 5

User preferences for energy feedback interface design

5.1 Introduction

This chapter presents the results of the questionnaire based survey conducted to understand user preferences on the types of information they prefer for residential energy feedback user interface. The user preferences were analyzed among young and middle-aged adults.

5.2 Survey data analysis

The data was statistically analyzed using both descriptive and inferential statistics. Descriptive statistics was used to summarize the data using frequency distribution tables and bar charts. Inferential statistics was used to test the hypothesis and check the statistical significance of the results.

The responses of the questionnaire include both nominal and ordinal type of data. We used non parametric statistical tests for both types of the data. Nominal data was tested using Chi Squared test for independence. A chi-squared test for independence compares two variables in a contingency table to see if they are related. In a more general sense, it tests to see whether distributions of categorical variables differ from each other. Post-hoc analysis was further conducted to determine if a specific row, column, or cell is largely driving the results (Beasley, 1995). For this, adjusted residuals were calculated for each cell, which is the raw residuals (or the difference between the observed counts and expected counts) divided by an estimate of the standard error. Residuals greater than ±1.96 show statistical significance.

5.3 Results

The presented results are ordered based on the critical parameters of energy feedback outlined in the literature review. Within subsections for each parameter, we first show the question asked to the participants and then present chi-square, post-hoc and descriptive data analysis results. The following are the findings obtained from the survey.

5.3.1 Feedback frequency

Question: Which of the following frequency of giving energy consumption feedback would you prefer?
The options for this question are shown in Figure 5.1.

Figure 5.1. Options for feedback frequency

			Daily	Weekly	Monthly	Not sure	Total
Age	Young	Count	28	70	79	13	190
		% within Age	14.70%	36.80%	41.60%	6.80%	100.00%
		Adjusted Residual	-3.4	1.1	1.7	0.1	
	Middle-aged	Count	72	81	86	17	256
		% within Age	28.10%	31.60%	33.60%	6.60%	100.00%
		Adjusted Residual	3.4	-1.1	-1.7	-0.1	
Total		Count	100	151	165	30	446
		% within Age	22.40%	33.90%	37.00%	6.70%	100.00%

Table 5.1. Age vs Feedback frequency

The participants prefer delayed monthly feedback over frequent feedback. However, middle-aged citizens prefer daily feedback more compared to young citizens (Figure 5.2). The Chi-Square test results indicate a significant difference between the two variables, $X^2(3, N = 446) = 11.476, p = 0.009$. Middle-aged citizens were more likely to choose feedback with daily frequency.

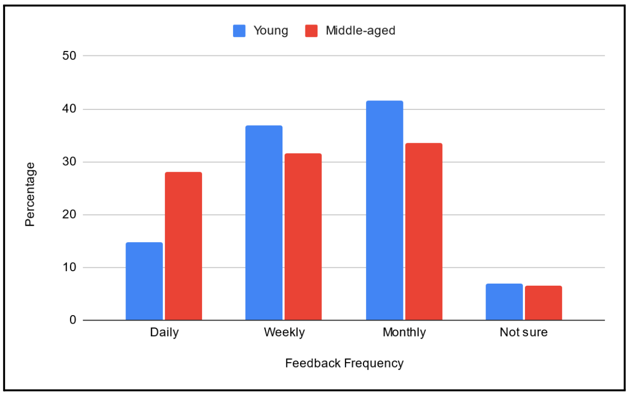

Figure 5.2. Feedback frequency

Post-hoc analysis results in Table 5.1 suggests that only daily feedback results are significant. Thus we can infer that Young adults prefer less daily feedback over Middle-aged adults.

5.3.2 Feedback medium

Question: What is your preferred medium for knowing the electricity consumption of your home?

Age group	Mobile Application	Electricity bills are sufficient	In-Home Display	Web Application	SMS	Printed Letter	Cumulative Responses
Young	103	69	59	60	38	22	351
Middle-aged	146	81	86	41	58	18	430

Table 5.2. Feedback medium frequency distribution

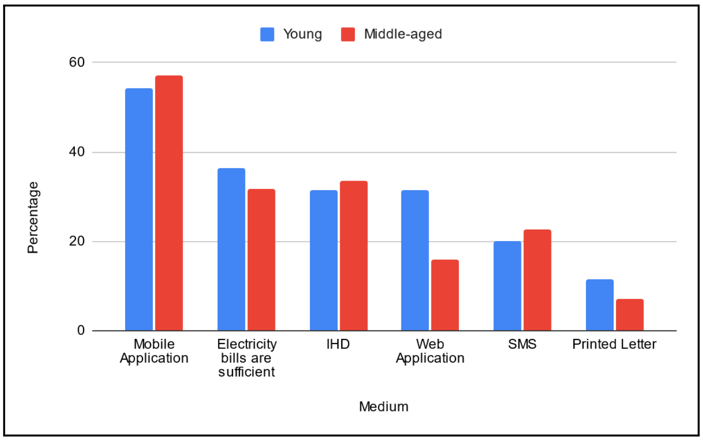

Figure 5.3. Feedback medium

This question was a multiple options select type. Table 5.2 shows the frequency distribution table with N=190 (young), N=256 (middle-aged). Figure 5.3 shows that in both the groups most participants would like to use a mobile application over IHDs or any other feedback medium for energy feedback.

			IHD		Total
			No	Yes	
Age	Young	Count	131	59	190
		% within Age	68.90%	31.10%	100.00%
		Adjusted Residual	0.6	-0.6	
	Middle-aged	Count	170	86	256
		% within Age	66.40%	33.60%	100.00%
		Adjusted Residual	-0.6	0.6	
Total		Count	301	145	446
		% within Age	67.50%	32.50%	100.00%

Table 5.3. Age vs Feedback medium (In-Home Display)

Post-hoc analysis results in Table 5.3 to Table 5.8 suggests that only results with "WebApp" as medium are significant. We can say that Young adults prefer more Web applications as a feedback medium over Middle-aged adults. Rest, both the age groups equally prefer Mobile applications over any other feedback medium.

			MobileApp		Total
			No	Yes	
Age	Young	Count	87	103	190
		% within Age	45.80%	54.20%	100.00%
		Adjusted Residual	0.6	-0.6	
	Middle-aged	Count	110	146	256
		% within Age	43.00%	57.00%	100.00%
		Adjusted Residual	-0.6	0.6	
Total		Count	197	249	446
		% within Age	44.20%	55.80%	100.00%

Table 5.4. Age vs Feedback medium (Mobile Application)

			WebApp		Total
			No	Yes	
Age	Young	Count	130	60	190
		% within Age	68.40%	31.60%	100.00%
		Adjusted Residual	-3.9	3.9	
	Middle-aged	Count	215	41	256
		% within Age	84.00%	16.00%	100.00%
		Adjusted Residual	3.9	-3.9	
Total		Count	345	101	446
		% within Age	77.40%	22.60%	100.00%

Table 5.5. Age vs Feedback medium (Web Application)

			Printed Letter		Total
			No	Yes	
Age	Young	Count	168	22	190
		% within Age	88.40%	11.60%	100.00%
		Adjusted Residual	-1.7	1.7	
	Middle-aged	Count	238	18	256
		% within Age	93.00%	7.00%	100.00%
		Adjusted Residual	1.7	-1.7	
Total		Count	406	40	446
		% within Age	91.00%	9.00%	100.00%

Table 5.6. Age vs Feedback medium (Printed Letter)

			SMS		Total
			No	Yes	
Age	Young	Count	152	38	190
		% within Age	80.00%	20.00%	100.00%
		Adjusted Residual	0.7	-0.7	
	Middle-aged	Count	198	58	256
		% within Age	77.30%	22.70%	100.00%
		Adjusted Residual	-0.7	0.7	
Total		Count	350	96	446
		% within Age	78.50%	21.50%	100.00%

Table 5.7. Age vs Feedback medium (SMS)

			Electricity Bills Are Sufficient		Total
			No	Yes	
Age	Young	Count	121	69	190
		% within Age	63.70%	36.30%	100.00%
		Adjusted Residual	-1	1	
	Middle-aged	Count	175	81	256
		% within Age	68.40%	31.60%	100.00%
		Adjusted Residual	1	-1	
Total		Count	296	150	446
		% within Age	66.40%	33.60%	100.00%

Table 5.8. Age vs Feedback medium (Electricity bills are sufficient)

5.3.3 Type of information

Users were asked to rate the information types based on their importance in the feedback interface.
Rate Scale: 1-5 (1: not important, 5: very important)
Options:

1. **Total consumption** of the house over time.
2. **Consumption** of **each room** of the house.
3. **Consumption** of **appliances** in the house.
4. **Real time consumption** of the house.
5. **Comparison** with the **past electricity consumption**.
6. **Comparison** with the **neighbours**.
7. **Tips/Advices** for energy saving.
8. **Consumption goals** to limit energy consumption.

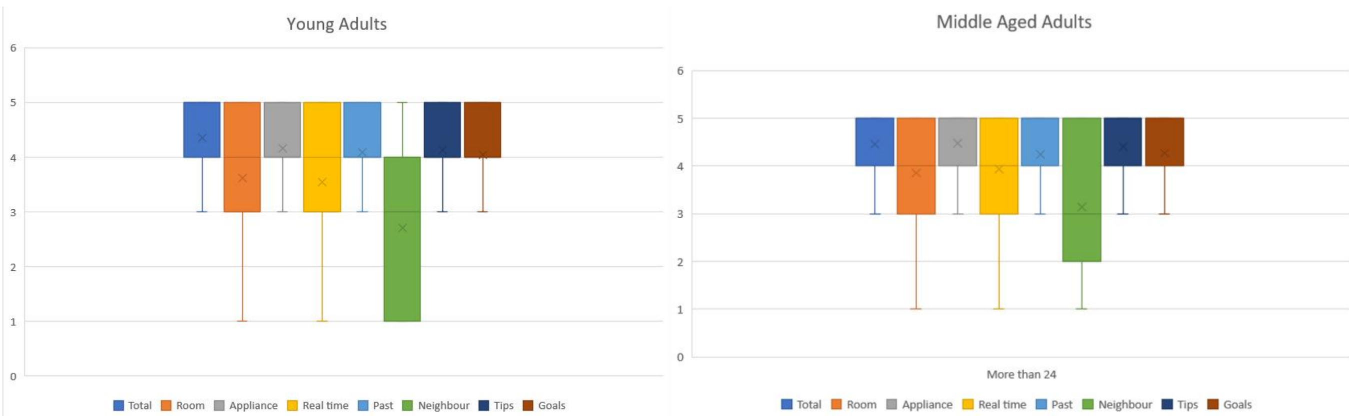

Figure 5.4. Type of information

As per Figure 5.4, in both the age groups total energy consumption, appliance level disaggregated information, tips, goals, and comparison with past consumption are the top five information types preferred by the users. Here, N=190 (young), N=256 (middle-aged). To limit the number of screens for the mobile application, the interface prototypes were designed for the top five information types.

Comparing the energy consumption with the neighbours was the least preferred information in both the age groups. This is a key result in the Indian context, as a lot of previous research insists on the effectiveness of Normative feedback in energy savings.

Information presentation

- Numerical presentation types

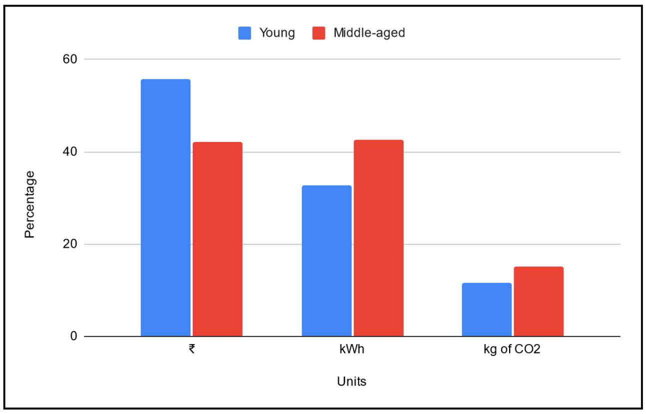

Figure 5.5. Numerical presentation types

Users were asked to rank the type of numerical presentation they prefer out of monetary, energy, and environmental units. Figure 5.5 shows that consumption presented in monetary terms i.e in ₹ units is equally preferred by both age groups. However the middle-aged elderly citizens would equally prefer to see their consumption in kWh units, this could be because the middle-aged group is more responsible for paying their household electricity bills and are more aware of the energy units. The Chi-Square test results indicate a significant difference between the two variables, $X^2(2, N = 446) = 8.085, p = 0.018$.

This is justified by the users' response to the questions asked about their energy literacy. 55/190 ~29% participants from the young age group, while 158/256 ~62% participants from the middle-aged group responded yes to the question: "Do you yourself pay the electricity bill of your house?". 114/190~60% participants from the young age group, while 174/256~68% participants from the middle-aged group responded yes to the question: "Does 1 unit of electricity mean the same as 1 kWh of electricity?"

			₹	kg of CO2	kWh	Total
Age	Young	Count	106	22	62	190
		% within Age	55.80%	11.60%	32.60%	100.00%
		Adjusted Residual	2.8	-1.1	-2.1	
	Middle-aged	Count	108	39	109	256
		% within Age	42.20%	15.20%	42.60%	100.00%
		Adjusted Residual	-2.8	1.1	2.1	
Total		Count	214	61	171	446
		% within Age	48.00%	13.70%	38.30%	100.00%

Table 5.9. Age vs Numerical presentation types

Post-hoc analysis results in Table 5.9 suggests that differences for ₹ and kWh units are significant, indicating young adults prefer ₹ units more as compared to middle aged adults.

			Yes	No	Sometimes	Total
Age	Young	Count	55	114	21	190
		% within Age	28.90%	60.00%	11.10%	100.00%
		Adjusted Residual	-6.9	6.1	1.3	
	Middle-aged	Count	158	79	19	256
		% within Age	61.70%	30.90%	7.40%	100.00%
		Adjusted Residual	6.9	-6.1	-1.3	
Total		Count	213	193	40	446
		% within Age	47.80%	43.30%	9.00%	100.00%

Table 5.10. Age vs Response to the question: “Do you yourself pay the electricity bill of your house?”

			Yes	No	I don't know	Total
Age	Young	Count	114	13	63	190
		% within Age	60.00%	6.80%	33.20%	100.00%
		Adjusted Residual	-1.7	-2.3	3.6	
	Middle-aged	Count	174	35	47	256
		% within Age	68.00%	13.70%	18.40%	100.00%
		Adjusted Residual	1.7	2.3	-3.6	
Total		Count	288	48	110	446
		% within Age	64.60%	10.80%	24.70%	100.00%

Table 5.11. Age vs Response to the question: "Does 1 unit of electricity mean the same as 1 kWh of electricity?"

Post-hoc analysis results in Table 5.10 and 5.11 suggests that the results are significant and indicates that middle-aged adults are more responsible for paying electricity bills of their house and young adults know less about energy units. This also tells middle-aged adults are more energy literate.

- Analogue presentation types

Question: Which of the following presentations do you think is more useful?
Figure 2.7 shows the option provided for this question.

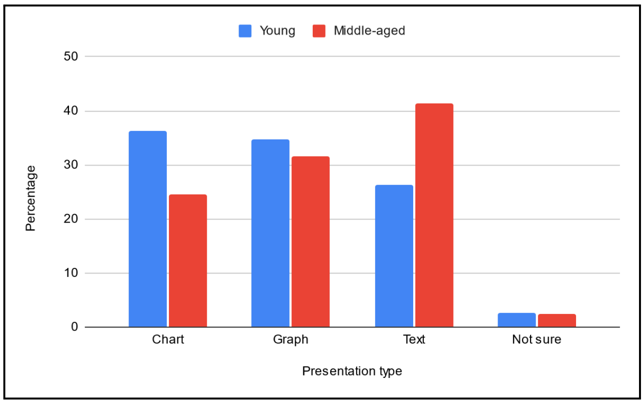

Figure 5.6. Analogue presentation types

The Chi-Square test results indicate a significant difference between the two variables, $X^2(3, N = 446) = 12.504$, $p = 0.006$. Figure 5.6 suggests that middle-aged citizens prefer text-based feedback over feedback presenting information in the form of a chart or graph. This could be because some types of charts and graphs require more time to understand.

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 [20]. However with age the capacity to handle this cognitive load decreases [18] and probably that's why middle-aged citizens prefer a more informative display.

Post-hoc analysis results in Table 5.12 suggests that results for Chart and Text type of presentation type are significant indicating young adults prefer charts more while middle-aged adults prefer text type of presentation for feedback.

			Chart	Graph	Not sure	Text	
Age	Young	Count	69	66	5	50	190
		% within Age	36.32	34.74	2.63	26.32	100
		Adjusted Residual	2.68	0.69	0.19	-3.3	
	Middle-aged	Count	63	81	6	106	256
		% within Age	24.61	31.64	2.34	41.41	100
		Adjusted Residual	-2.68	-0.69	-0.19	3.3	
Total		Count	132	147	11	156	446
		% within Age	29.6	32.96	2.47	34.98	100

Table 5.12. Age vs Analogue presentation types

- Ambient presentation types

The users were asked to rank the ambient presentation types based on their preferences. Figure 2.8 shows some of the examples of ambient presentation types.

The Chi-Square test results didn't indicate a significant difference between the two variables, $X^2(3, N = 446) = 3.372$, $p = 0.338$. As per Figure 5.7, both the age groups prefer Emoji/Smiley over any other ambient presentation types, thus the designed prototypes also include happy/sad emojis to demonstrate good vs bad consumption behaviour.

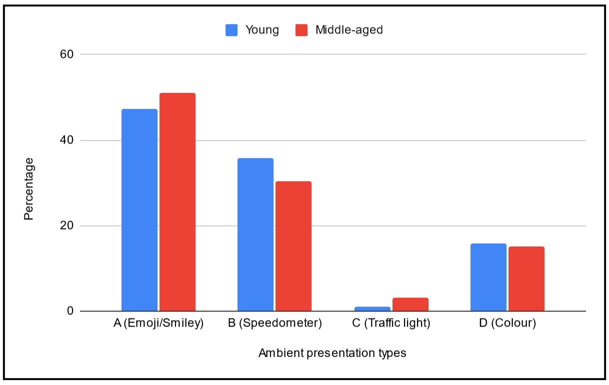

Figure 5.7. Ambient presentation types

			A (Emoji/Smiley)	B (Speedometer)	C (Traffic light)	D (Colour)	Total
Age	Young	Count	90	68	2	30	190
		% within Age	47.40%	35.80%	1.10%	15.80%	100.00%
		Adjusted Residual	-0.8	1.2	-1.5	0.2	
	Middle-aged	Count	131	78	8	39	256
		% within Age	51.20%	30.50%	3.10%	15.20%	100.00%
		Adjusted Residual	0.8	-1.2	1.5	-0.2	
Total		Count	221	146	10	69	446
		% within Age	49.60%	32.70%	2.20%	15.50%	100.00%

Table 5.13. Age vs Ambient presentation types

Post-hoc analysis results in Table 5.13 suggests that results are not significant for any of the cells.

5.4 Discussion and Conclusion

We conducted a questionnaire survey to understand user preferences of participants of two age groups: young adults (18-24 years old) and middle aged adults (25-45 years old). We compared results of the survey on the key parameters of energy feedback: feedback frequency, feedback medium, type of information and presentation type. (Moura, 2019) also conducted a similar survey in the Brazilian context with Children (11-13 years old), Adults(18-65 years old) and Elderly (More than 65 years old) groups. Since age groups are different, results can't be compared directly. However, we can state the results of similar questions asked by them. They found elderly citizens prefer less informative information as compared to adults and they prefer basic text based information type then other forms of information type.

This chapter provided us the results of the questionnaire based survey conducted to understand user preferences on the types of information they prefer for residential energy feedback user interface. Data analysis results from this chapter were used in the next chapter to design User Interface prototypes for young and middle aged adults.

Chapter 6

Energy feedback user interface design

6.1 Introduction

Interface design for energy feedback requires specific considerations that distinguish it from other UI designs. Thera are some key differences which make Interface design for Energy feedback different from other UI designs.

- **Focus on Behavioral Change:**

  Energy feedback interfaces often aim to motivate users to adopt more energy-efficient behaviors. Therefore, the design should incorporate motivational elements, such as goal-setting, achievements, and real-time feedback, to encourage users to make sustainable choices.

- **Real-time Data Presentation:**

  Unlike many other interfaces, energy feedback designs need to provide dynamic and real-time data on energy consumption. Users should be able to see immediate changes in consumption based on their actions, providing a sense of control.

- **Environmental Context:**

  Energy feedback interfaces may benefit from displaying contextual information about the environmental impact of energy consumption. This could include carbon footprint calculations, helping users connect their energy use to broader sustainability goals.

- **Gamification and Rewards:**

  Introducing gamification elements, such as badges, rewards, or challenges, can be effective in energy feedback interfaces to make the experience more enjoyable and encourage long-term engagement. This is less common in many other UI designs.

- **Comparative Data:**

  Energy feedback interfaces often involve comparing a user's energy consumption to benchmarks or similar households. This social comparison aspect is less prevalent in many other UI designs and can influence user behavior.

- **Long-term Behavior Change Goals:**

  Energy feedback interfaces often draw on principles of behavioral psychology to encourage lasting changes in user behavior. This involves understanding and addressing cognitive biases, habits, and motivations, which may not be as critical in other UI design contexts.

- **Integration with Smart Home Devices:**

  Energy feedback interfaces may need to integrate with smart home devices to provide a comprehensive view of energy usage. This adds a layer of complexity and unique design challenges not present in all UI designs.

Thus, interface design for energy feedback goes beyond traditional UI design by emphasizing behavioral change, real-time data presentation, and gamification. Understanding the specific goals of promoting energy efficiency and sustainability is crucial in shaping the design approach. In this chapter we present the energy feedback user interface prototypes designed based on the questionnaire based survey conducted on young and middle-aged participants. Further we discuss the second questionnaire survey conducted on the same focus group for validation of the designed screen. We present its results and later discuss the key findings from this study.

6.2 Interface design

This study highlighted the need to develop guidelines for the design of visual devices for different types of users, in the Indian context. To reduce energy consumption, it is necessary that the user is motivated to save energy and has an understanding of the information presented on the device. Therefore, it is necessary to investigate which information elements should be included in the device so that the user can understand and reduce its consumption.

The results from chapter 5 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 adults indicated a preference for more detailed information, including delayed feedback frequency and energy information in monetary units. As shown in Figure 6.1, the mobile interface design for young adults reflects these preferences. In contrast, middle-aged adults favored simple text-based feedback with minimal information, including energy consumption displayed in both monetary and energy units. Figure 6.2 illustrates the mobile interface design catering to the preferences of middle-aged adults. Figure 6.3 displays some alternate screen designs that cater to the similar preferences of both age groups.

Figure 6.1. Mobile application interface prototypes for the young adults

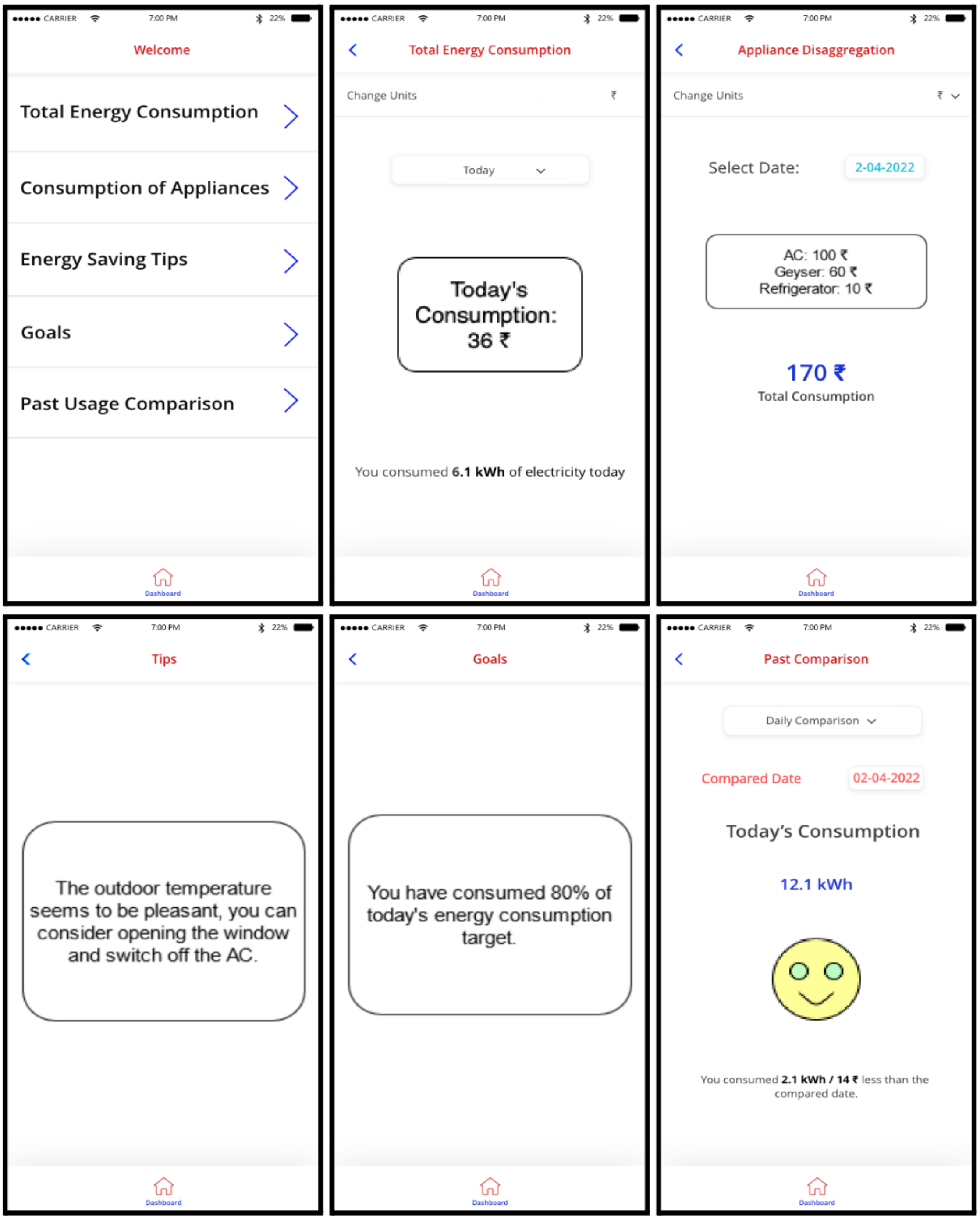

Figure 6.2. Mobile application interface prototypes for middle-aged adults

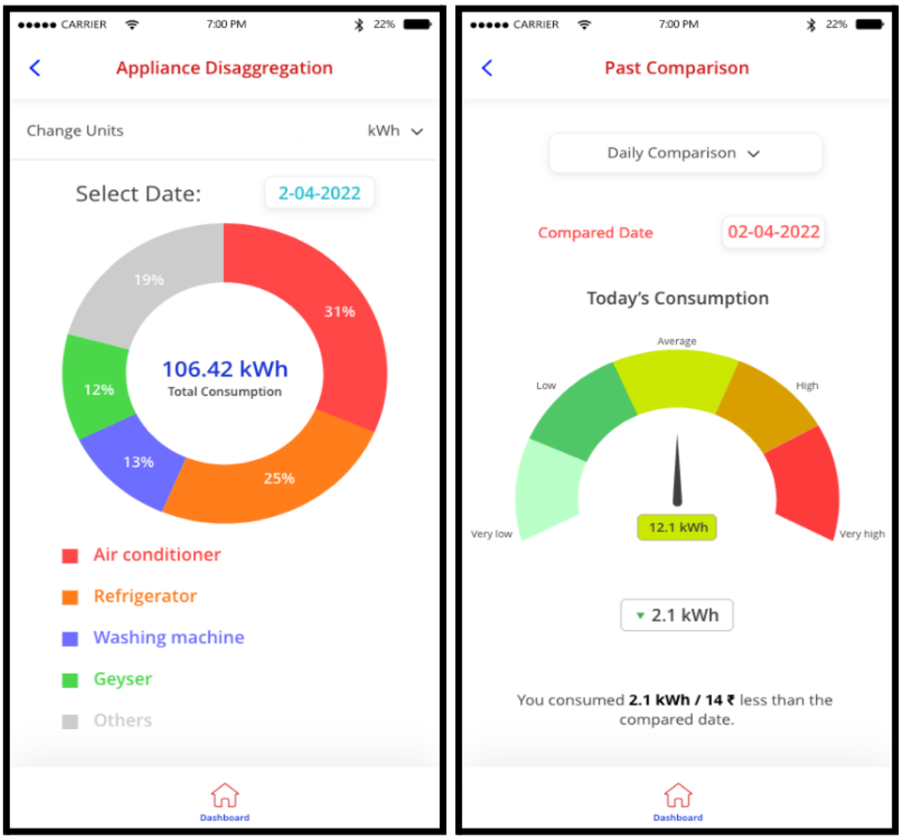

Figure 6.3. Generalized screen designs that can be used for both the age groups

6.3 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 6.4 displays the various options presented to participants, which included different combinations of 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 (Figure 6.5) 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".

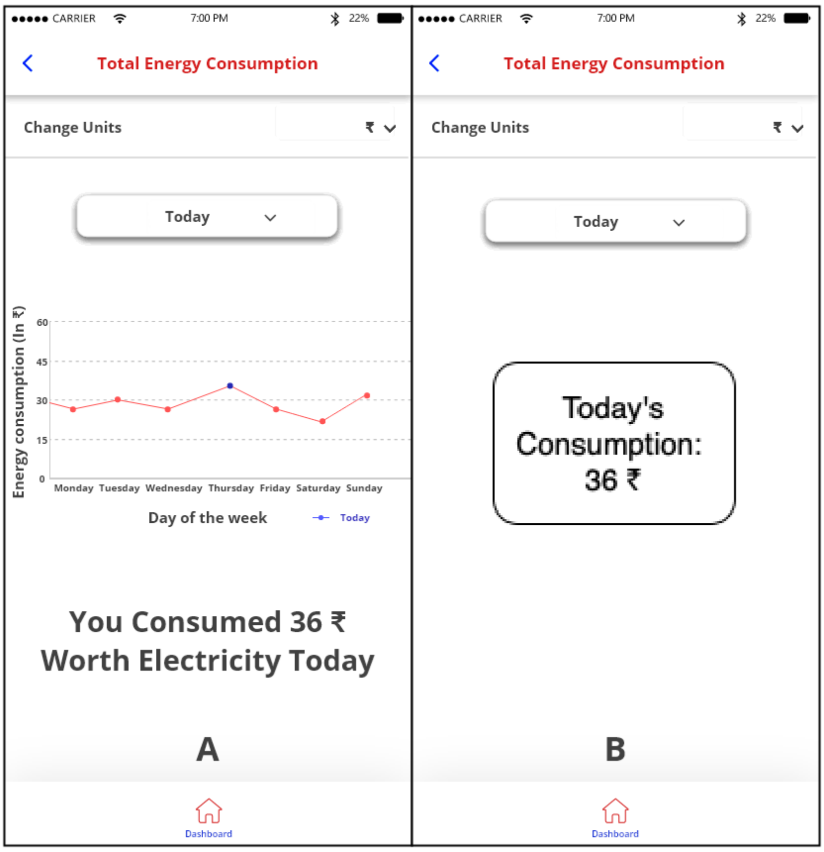

Figure 6.4. Options for showing total energy consumption

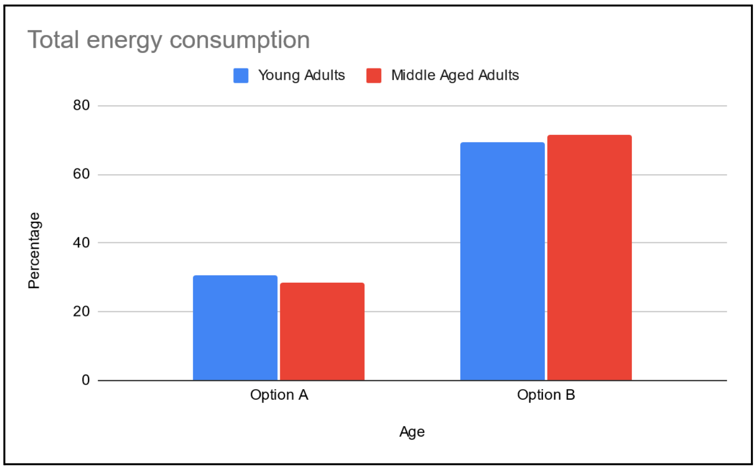

Figure 6.5. Validation results for total energy consumption

The second question in the second survey asked participants to compare options for displaying appliance-level disaggregated information. Figure 6.6 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 graphi- cal presentation, while middle-aged adults preferred option C with a more generalized display (Figure 6.7). 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.

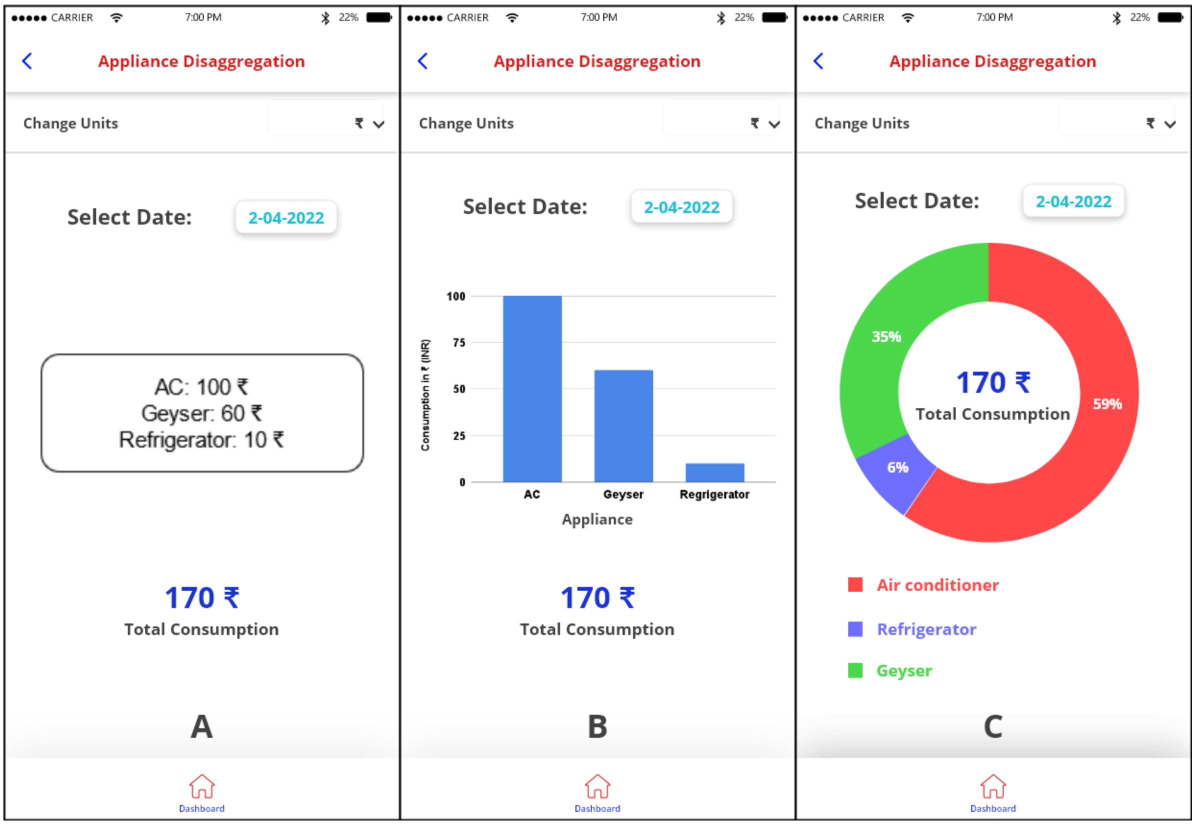

Figure 6.6. Options for showing disaggregated consumption

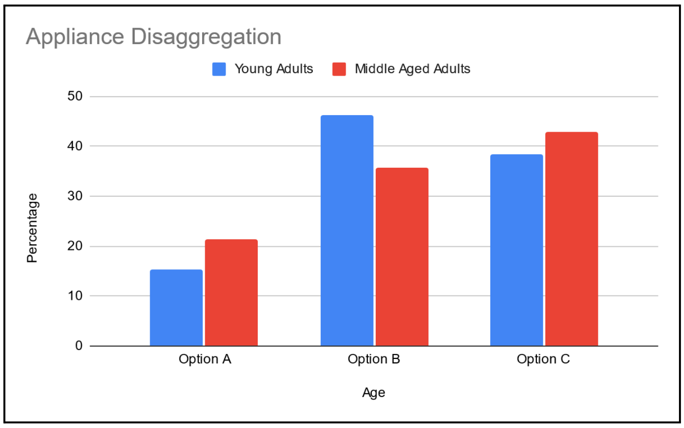

Figure 6.7. Validation results for disaggregated

The third question in the second survey asked participants to compare options for displaying energy-saving tips to users. Figure 6.8 displays the options presented to participants, which varied in the amount of information displayed on the screens. The results (Figure 6.9) 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.

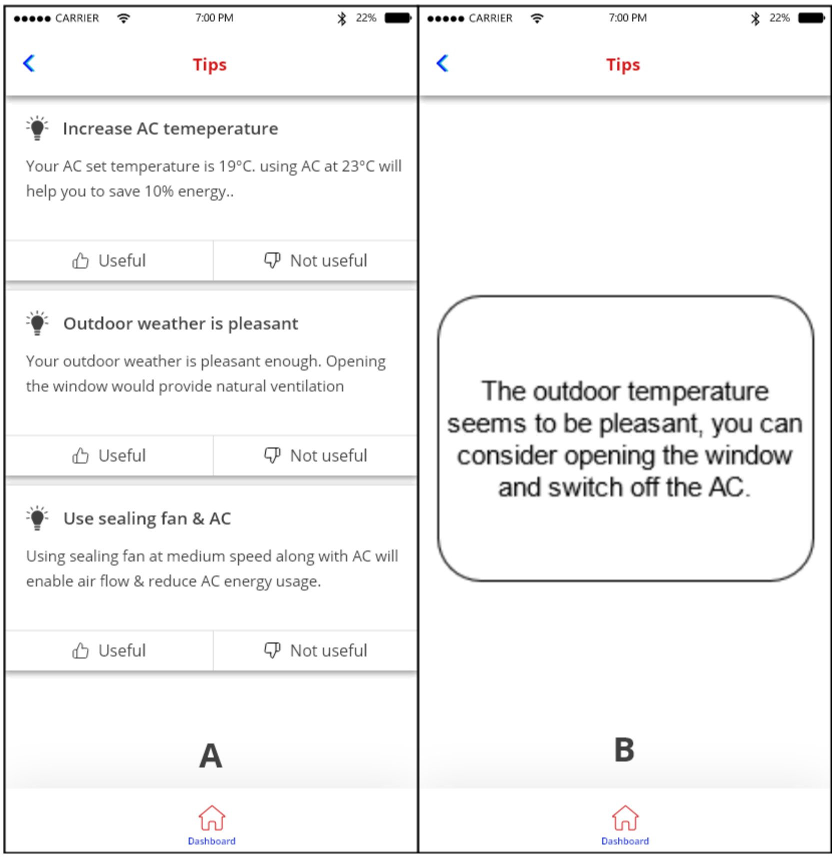

Figure 6.8. Options for showing Tips

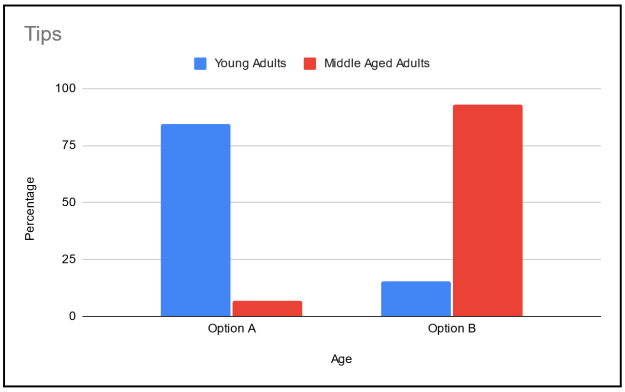

Figure 6.9. Validation results for Tips

The fourth question in the second survey compared options for displaying energy-saving goals/targets to users. Figure 6.10 displays the options presented to participants, which also varied in the amount of information displayed on the screens. The results (Figure 6.11) 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.

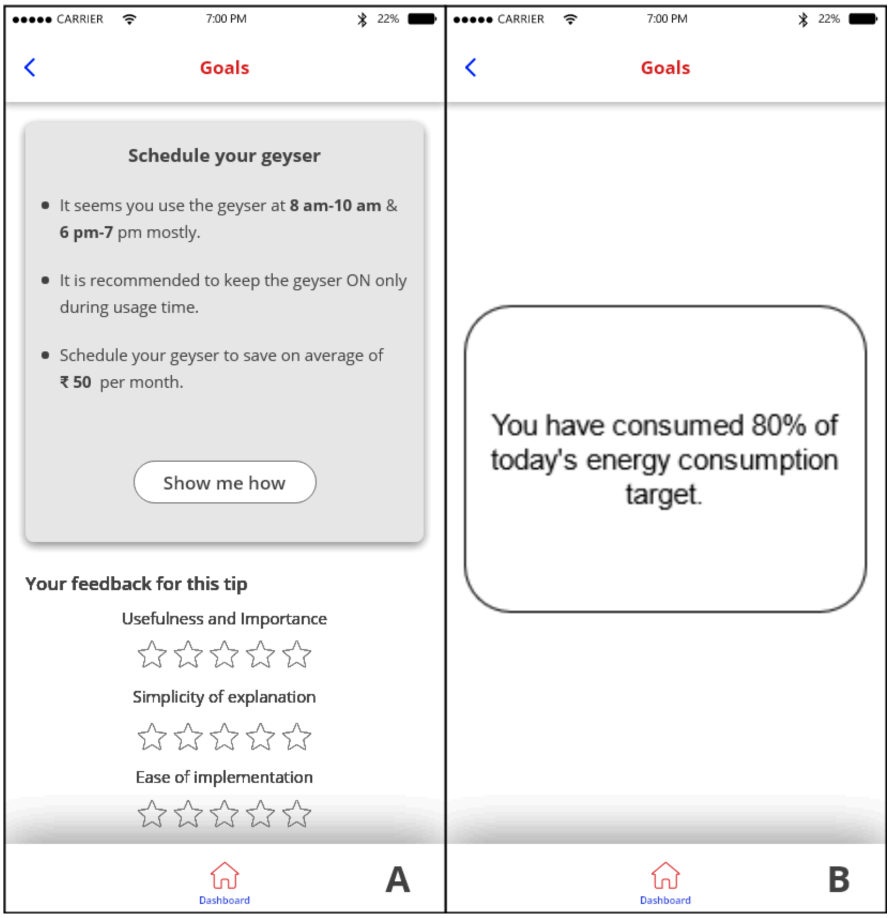

Figure 6.10. Options for showing Goals

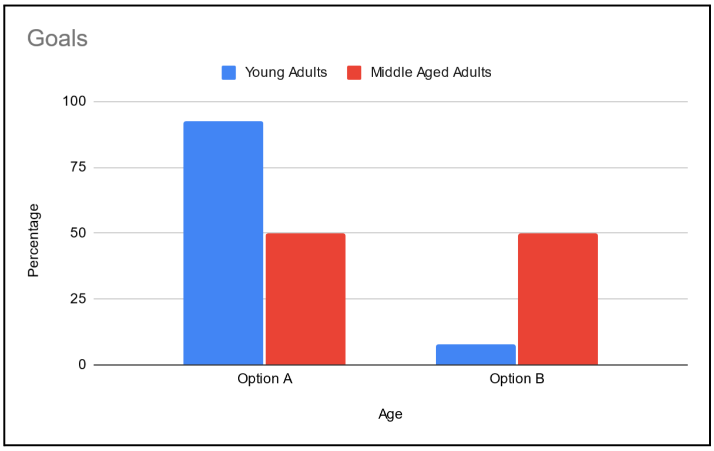

Figure 6.11. Validation results for Goals

The final question in the second survey compared options for historic energy consumption comparison. Figure 6.12 displays the options presented to participants, which compares the use of ambient presentation types and the amount of information displayed on the screens. The results (Figure 6.13) 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.

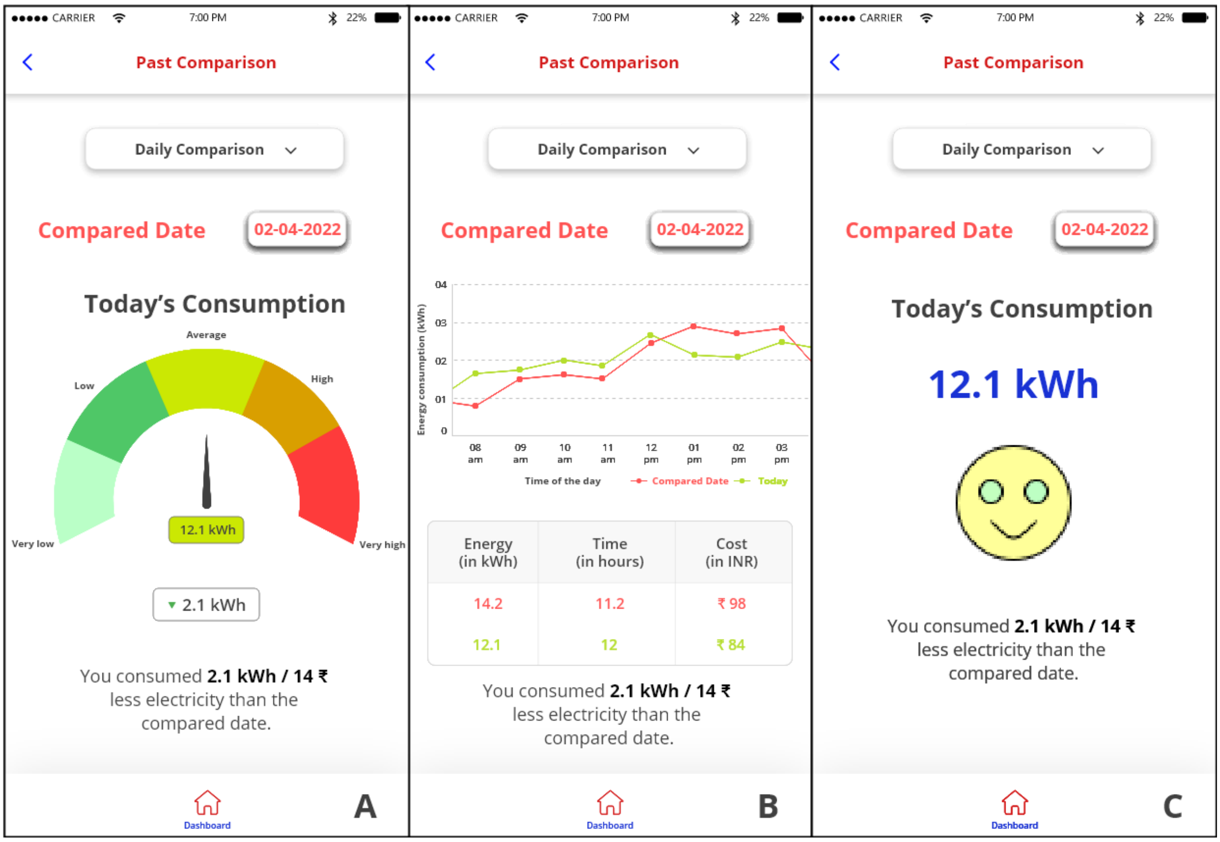

Figure 6.12. Options for showing past consumption comparison

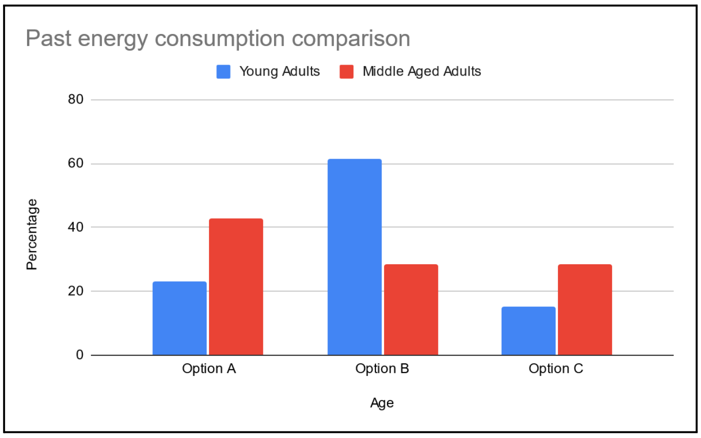

Figure 6.13. Validation results for past consumption

6.4 Discussion and conclusion

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 questions. 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 com- parison 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 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 presenta- tion 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 on assessing 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.

Chapter 7

Conclusion

We reviewed 33 studies which have carried out field experiments by monitoring energy use and quantitatively measuring the change in energy consumption caused due to an energy feedback intervention. These studies have been carried out in different geographical locations, providing varying feedback information using diverse ways, among members with varying levels of interest and motivation for saving energy, using different experimental techniques. Through the review we have observed the following:

- The intention behind providing feedback is to make energy consumption more visible to the users so that they know how they are consuming energy and take appropriate measures to reduce the consumption.
- The heterogeneous nature of the studies makes it difficult to conclude the exact cause for achievement in energy savings.
- An effective energy feedback system is one that gives households the required data about their energy consumption, is easy to use and does not involve extensive pre-requisites or complications in the interface and excites the householders. An informative, user-friendly, and attractive system would result in increased interest and interactions, leading to greater energy awareness and potentially resulting in more informed decisions for reduced energy use. The last two decades have witnessed studies being driven towards providing online feedback that is real-time in nature. This is due to technological advancements in computing, IoT, Artificial Intelligence-Machine Learning, among others, feedback is evolving.
- The feedback information is evolving from simple (kWh, cost, CO_2 emissions) and detailed information to personalized actionable tips and actions, Future estimates, and their impact on energy savings. This has been possible with the availability of low-cost hardware and software. Simple text-based feedback conveying energy consumption and cost are popular information types provided as feedback. Recent studies provided simple text-based feedback through an IHD, conveying that simple text-based feedback is still an important or popular feedback information type and can enable energy conservation merely by using an IHD along with a traditional printed bill.
- While most studies have achieved energy savings due to energy feedback, few have also shown a rebound effect where energy consumption has increased. It is observed that over time people add new appliances in their house, so even if they develop a habit of energy saving the new products may add up to overall increase in the consumption.
- Studies have shown calculated energy savings diminish over the duration of study. Across the reviewed studies we have observed lower savings in studies over a large duration (greater than 1 year). This trend may probably be because energy feedback has an impact on household energy consumption in the initial phases of a study. It has also been observed that people’s engagement with the equipment reduces over time. A simplistic or actionable energy feedback might be capable of impacting users' energy consumption but often the user loses interest in the activity.
- Studies with a large sample size (above 1000 households) show lower energy savings. This may be attributed to the averaging of savings among a large group due to multiple reasons such as level of interest, level of awareness and behavioral aspects.

- Feedback studies provide policy support for energy-efficient building codes and standards. It also helps in providing energy saving tips to homeowners to adopt energy-efficient practices, as well as regulations that require new homes to meet certain energy efficiency standards.

Our work aimed to design mobile application interfaces that can increase energy savings through effective feedback. The findings from the review conducted on field studies suggested that energy feedback has an impact on energy savings. To design user interfaces in the Indian context, we examined the user preferences for energy feedback based on focus groups with 446 participants (190 young and 256 middle-aged), using a questionnaire-based survey. We analyzed the survey responses using the Chi-Square Test of Independence to determine the relationship between user preferences for feedback information and age groups. Post-hoc analysis was further conducted to determine if a specific row, column, or cell is largely driving the results. 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 the form of Emoji/Smiley over any other ambient presentation type.

Based on research findings, we designed mobile application interface prototypes that meet users' preferences for feedback information. We further validated the designed prototypes with 27 participants (who opted for future participation in the study) 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.

Chapter 8

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.

Related publications

- Agarwal, R., Garg, M., Tejaswini, D., Garg, V., Srivastava, P., Mathur, J., & Gupta, R. (2023). A review of residential energy feedback studies. *Energy and Buildings*, *290*(June 2022), 113071. https://doi.org/10.1016/j.enbuild.2023.113071
- Garg, M., Agarwal, R., Garg, V., & Srivastava, P. (2023). Interface design for residential energy feedback , in Indian context . *Energy Informatics*, *6*(1), 1–28. https://doi.org/10.1186/s42162-023-00267-2

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Appendix A

Interface Design for Energy Feedback

* Required

Participant Consent Form

Hello,

Thank you so much for offering your time. There are some details that we need from you before you start the survey.

Please read the following description carefully and agree if you volunteer for this survey.

What you will be doing: This survey is intended to understand the impact of user awareness about their household energy consumption (and other factors) on the type of feedback they prefer. You have to answer 28 questions based on your understanding and preferences for residential energy feedback. Details about technical terms used in the survey are explained in-between each section.

Time Requirements: Participation will take approx 10 to 15 minutes.

Risks: There are no anticipated risks in participation.

Confidentiality: Your participation will remain confidential. Your name and any personal details will not be stored with the data, and the assigned participant ID will be used in all places to reference your data.

Participation & Withdrawal: Participation is voluntary and you may withdraw at any point.

To contact the Researcher: If you have questions about this research, please contact the principal researcher: Madhur Garg (madhur.garg@research.iiit.ac.in)

1. I have read the above information. I understand the type of date being collected in this study and the reason for its collection. Thus, I hereby give consent to participate in this study. *

   Check all that apply.

   ☐ **(I agree)**

Project Partners:

Funded By:

General Demographics

2. What is your age? *

Mark only one oval.

- 18-24 years old
- 25-44 years old
- 45-64 years old
- 65 years or older

3. What is your gender? *

Mark only one oval.

- Male
- Female
- Prefer not to say
- Other: ____________________

4. Which city are you currently living in? *

____

5. What is the highest degree you have completed/pursuing? *

Mark only one oval.

- Primary Education
- Secondary Education (11th/ 12th)
- Diploma
- Graduation
- Post Graduation
- Vocational and training schools
- Other: ____________________

6. What is your educational background? *

Mark only one oval.

- Art/ design
- Business/ commerce
- Science
- Medical
- Other: ____________________

7. How many people live in your home? (including yourself) *

Mark only one oval.

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- More than 10

8. How many ACs do you have in your home? *

Mark only one oval.

- 0
- 1
- 2
- 3
- More than 3

9. How many Geysers do you have in your home? *

Mark only one oval.

- 0
- 1
- 2
- 3
- More than 3

10. What is your approximate monthly electricity bill (in ₹) in Summer? *

Mark only one oval.

- Less than 1000
- 1000 to 2000
- 2000 to 5000
- 5000 to 10000
- More than 10000

Energy Awareness

11. What do you think is the average cost of 1 unit of residential electricity? *

(approximately in ₹)

12. Do you check for calculation mistakes in your electricity bills? *

Mark only one oval.

- Yes
- No
- Sometimes

13. Do you yourself pay electricity bill of your house? *

Mark only one oval.

- Yes
- No, someone else in the family pays it
- Sometimes

14. Does 1 unit of electricity means the same as 1 kWh of electricity? *

Mark only one oval.

- Yes
- No
- I don't know

15. What is the major source of electricity in India? *

Mark only one oval.

- Coal
- Hydro (water)
- Solar
- Wind
- Oil
- Nuclear

16. What information do you usually check in your electricity bills? *
(you can select multiple options)

Check all that apply.

- Amount to be paid
- Consumed energy
- Usage comparison
- I don't check my electricity bill

17. In your opinion, what feature(s) does a "Smart Home Energy Management System" has? *
(you can select multiple options)

Check all that apply.

- Helps in saving household energy
- Turn appliances on and off remotely
- Set appliances to operate on schedules
- Not sure

18. Which one of these devices do you think contribute maximum to your electricity bill (excluding AC)? *

Mark only one oval.

- Washing Machine
- Refrigerator
- Geyser
- Oven
- Dishwasher
- TV
- Other: ____________

19. What motivates you to save energy?

Mark only one oval.

- Electricity cost
- Environmental impact
- Social influence
- There is no motivation to save energy
- Other: ____________

Electricity Feedback

Electricity feedback is the information provided to you about the electricity consumption of your house. The intention behind providing feedback is to make energy consumption more visible.

Example: The electricity bills we receive are paper-based electricity feedback. As feedback, it gives total energy consumption of the house, equivalent cost, and comparison with past months.

20. Do you have any electricity feedback system at your home other than electricity bills? (Yes/No) *

If yes, then please mention the feedback system you use

21. What is your preferred medium for knowing the electricity consumption of your home? *

(you can select multiple options)

Check all that apply.

- [ ] In-Home-Display (a tablet or any screen used to monitor houshold energy)
- [ ] Mobile Application
- [ ] Web Application (for viewing on computer)
- [ ] Printed Letter
- [ ] SMS
- [ ] Electricity bills are sufficient

Other: [ ]

22. What appliance(s) in your home would you be interested in getting the appliance level electricity consumption? *

(you can select multiple options)

Check all that apply.

- [ ] AC
- [ ] Refrigerator
- [ ] Washing Machine
- [ ] Geyser
- [ ] Dish Washer
- [ ] TV
- [ ] Oven

Other: [ ]

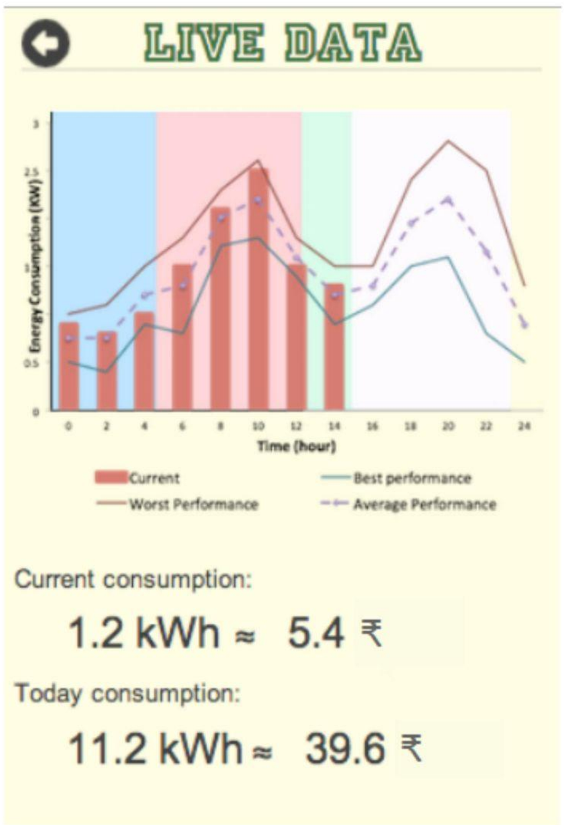
23. How frequent is it convenient for you to receive notifications about your electricity consumption? *

Mark only one oval.

- Multiple times a day
- Once a day
- Once a week
- Once in two weeks
- Once a month
- Once a year

Electricity Feedback Interface

A feedback interface communicates the electricity consumption information of your home to you. This is how a typical feedback interface looks like:



We are designing interface for an energy feedback mobile app. Please let us know your preferences about the interface in the next set of questions.

Electricity Consumption

Following are some options of displaying information about daily **electricity consumption** of a home:

5 kWh	5 kg of CO_2 emissions	30 ₹

24. **Rank** the above options based on your preferences. *

Mark only one oval per row.

	kWh	kg of CO2	₹
1st Rank (best)			
2nd Rank (average)			
3rd Rank (worst)			

25. Which of the following frequency of giving energy consumption feedback would you prefer? *

Mark only one oval.

Monthly

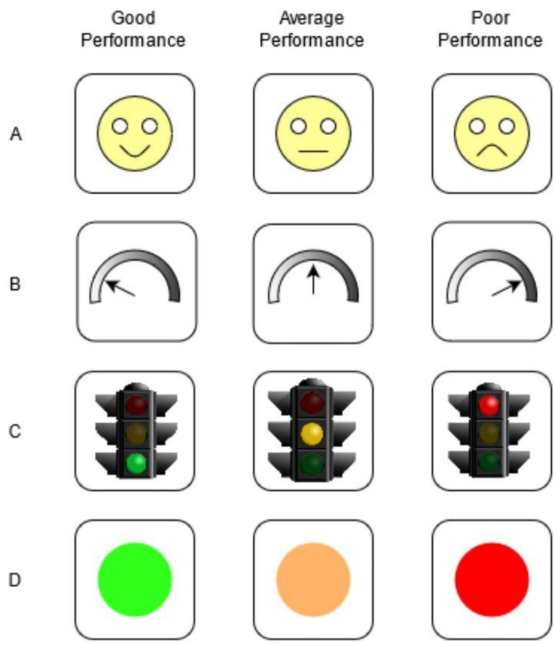
Weekly

Daily

Not sure

Electricity Performance

Following are some indicators of displaying the overall energy **performance** of a home:



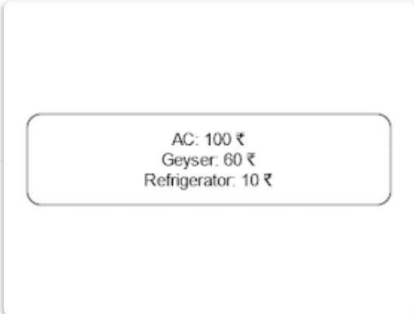
26. **Rank** the above indicators based on your preferences. *

Mark only one oval per row.

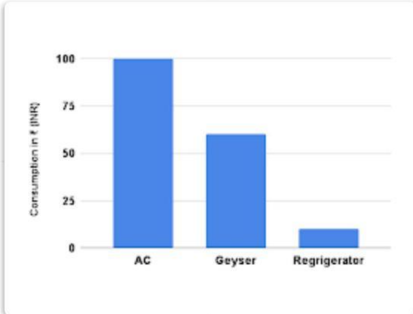
	A (Emoji/Smiley)	B (Speedometer)	C (Traffic light)	D (Colour)
1st Rank (best)	⬭	⬭	⬭	⬭
2nd Rank (good)	⬭	⬭	⬭	⬭
3rd Rank (average)	⬭	⬭	⬭	⬭
4th Rank (worst)	⬭	⬭	⬭	⬭

27. Which of the following presentation do you think is more useful? *

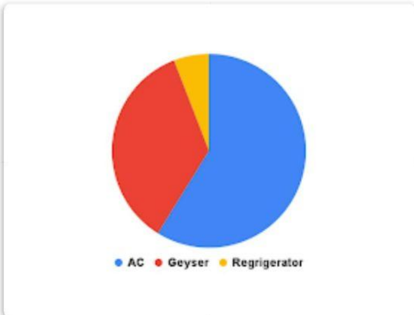
Mark only one oval.



- Text



- Graph



- Chart
- Not sure

Rate the importance of each information

Rate the following information based on their importance in electricity consumption feedback interface.

28. **Total consumption** of the house over time. Example (total month's consumption in ₹ would look like the following): *

Monthly Consumption: 1000 ₹

Mark only one oval.

	1	2	3	4	5	
Not Important	◯	◯	◯	◯	◯	Very Important

29. **Consumption** of **each room** of the house. Example (one day consumption in ₹ for 1 BHK apartment): *

Bedroom: 50 ₹
Bathroom: 20 ₹
Kitchen: 10 ₹

Mark only one oval.

	1	2	3	4	5	
Not Important	◯	◯	◯	◯	◯	Very Important

30. **Consumption** of **appliances** in the house. Example (One day consumption in ₹ would look like the following): *

AC: 100 ₹
Geyser: 60 ₹
Refrigerator: 10 ₹

Mark only one oval.

	1	2	3	4	5	
Not Important	◯	◯	◯	◯	◯	Very Important

31. **Real time consumption** of the house. Example (current consumption in ₹ per hour would look like the following): *

You are currently consuming: 40 ₹ per hour

Mark only one oval.

	1	2	3	4	5	
Not Important	⬭	⬭	⬭	⬭	⬭	Very Important

32. **Comparison** with the **past electricity consumption** . Example (weekly comparison in ₹ would look like the following): *

Last week: 100 ₹
This week: 60 ₹

Mark only one oval.

	1	2	3	4	5	
Not Important	⬭	⬭	⬭	⬭	⬭	Very Important

33. **Comparison** with the **neighbours**. Example (one day comparison in ₹ would look like the following): *

Your house: 100 ₹
Average neighbours' consumption: 60 ₹

Mark only one oval.

	1	2	3	4	5	
Not Important	⬭	⬭	⬭	⬭	⬭	Very Important

34. **Tips/Advices** for energy saving. Example: *

> The outdoor temperature seems to be pleasant, you can consider opening the window and switch off the AC.

Mark only one oval.

	1	2	3	4	5	
Not Important	◯	◯	◯	◯	◯	Very Important

35. **Consumption goals** to limit energy consumption. Example: *

> You have consumed 80% of today's energy consumption target.

Mark only one oval.

	1	2	3	4	5	
Not Important	◯	◯	◯	◯	◯	Very Important

Appliance Shifting Behaviour

In India, electricity demand is usually high during the day and evening. Late night and early morning demand is generally low. Using non-essential appliances during peak time increases stress on the energy grid and leads to increased energy pricing.

36. What could motivate you to use a washing machine during late night/early morning instead of day/evening time? (you can select multiple options) *

Modern washing machines can be put on a timer so that they will automatically operate during late night/early morning.

Check all that apply.

- [ ] Penalty of 3 ₹ per wash cycle for using it during the day/evening
- [ ] Discount of 8 ₹ per wash cycle for using it during late night/early morning
- [ ] Free electricity for using it during late night/early morning
- [ ] We will plant one tree per month on your behalf, if you use it during late night/early morning
- [ ] None of the above

Other: [ ] ______________________

37. What could motivate you to change the temperature of AC to 26 deg Celsius or above? *

(you can select multiple options)

Check all that apply.

- [ ] Penalty of 6 ₹ per hour if AC temperature is less than 25 deg celsius
- [ ] Discount of 6 ₹ per hour if AC temperature is greater than 25 deg celsius
- [ ] Free electricity for the time AC temperature is greater than 25 deg celsius
- [ ] We will plant one tree per month if you keep the temperature above 25 deg celsius
- [ ] None of the above

Thank You

38. Which device did you use to fill this survey? *

Mark only one oval.

- ( ) Mobile phone
- ( ) Laptop/ PC
- ( ) Tablet
- ( ) Other: ______________________

39. Please select all the options you are interested in:

Check all that apply.

- [ ] Early access to study findings
- [ ] Participate in follow up survey

40. Please provide your email address, if you are interested in any of the above options. (Note that this is not mandatory)

We will not map your response with your email address and will not disclose it.

You can now submit and end this experiment. Thank you so much for participating.

Appendix B

Interface Design for Energy Feedback

* Required

Participant Consent Form
Hello,

Thank you so much for offering your time. There are some details that we need from you before you start the survey.

Please read the following description carefully and agree if you volunteer for this survey.

What you will be doing: This survey is intended to understand the impact of user awareness about their household energy consumption (and other factors) on the type of feedback they prefer. You have to answer 28 questions based on your understanding and preferences for residential energy feedback. Details about technical terms used in the survey are explained in-between each section.

Time Requirements: Participation will take approx 10 to 15 minutes.

Risks: There are no anticipated risks in participation.

Confidentiality: Your participation will remain confidential. Your name and any personal details will not be stored with the data, and the assigned participant ID will be used in all places to reference your data.

Participation & Withdrawal: Participation is voluntary and you may withdraw at any point.

To contact the Researcher: If you have questions about this research, please contact the principal researcher: Madhur Garg (madhur.garg@research.iiit.ac.in)

1. I have read the above information. I understand the type of date being collected in this study and the reason for its collection. Thus, I hereby give consent to participate in this study. *

   Check all that apply.

   ☐ **(I agree)**

Appendix C

International Institute of Information Technology, Hyderabad, India

Institute Review Board Committee Action Form

Date	25-June-2021
Proposal ID and Number	IIITH-IRB-PRO-2021-03
Study Title	Interface design for residential energy feedback [Proposal submitted on 26-May-2021]
Principal Investigator (applicable to faculty only) In case of student's application, supervisor's approval would be required	Vishal Garg (Faculty)
Research Group/ Lab	Center for IT in Building Science, IIIT Hyderabad
Decision, remarks on following points	**The proposal is approved in the current form.** Online questionnaire-based survey will be conducted to learn about the levels of energy literacy, driving factors, and motivation for energy conservation in residences in India. Data collection is expected to continue till January 2022. Study is funded by DST, GoI.
- Sample definition and consent form - Anonymity (participation) - Participation compensation / reward – as monetary/ credits/ no rewards - Stimuli subjected to the participants - Any Psychological/ Physical/ Biological risks - If Yes, the kind of risk	Observations made from the proposal: • Consent Process is mentioned • Anonymity/ confidentiality plan mentioned • No rewards • No harmful stimuli • No perceivable risks
Recommendation / Suggestion (if any)	No Suggestions.
Inquiry (if any)	No Inquiry.
Name and Signature of IRB member/ Chair	S. Bapi Raju Professor Cognitive Science Lab International Institute of Information Technology, Hyderabad, Gachibowli, Telangana, India 500 032