A review of residential energy feedback studies

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ABSTRACT

Residential energy feedback is about providing personalized information on household energy use to consumers to encourage energy savings. This paper conducts a review of field based studies that have evaluated the impact of energy feedback on residential energy consumption. The review includes studies in real occupied homes that have deployed feedback intervention(s) and measured energy savings. Our study builds a taxonomy for energy feedback studies based on different *characteristics* of feedback such as frequency, type, presentation style, and methods of access. Energy savings from similar feedback types were found to differ depending on how the study was conducted. The reviewed studies deployed a range of feedback information 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.

The duration of studies varied widely, ranging from one month to three years and revealed potential energy savings between 5% and 20%. While most studies achieved energy savings due to energy feedback, a few of them reported a increase in energy consumption which could be due to rebound effect. Most of the studies provided current and historical electricity consumption. Others used Randomized Control Trial (RCT) design, comparing energy consumption and savings information with neighbours. Most of the studies were conducted in developed countries with cold climates, with a shift towards providing real-time online feedback over the last two decades. There was lack of large-scale studies on residential energy feedback in emerging economies where growth of air conditioning is happening. These studies might also consider the human behavior and cultural influences while evaluating impact of energy feedback. Our recommendation is that the academic and policy community address this gap since energy feedback is likely to stimulate positive energy behavior change amongst householders leading to energy savings.

KEYWORDS
residential energy consumption, residential energy feedback, residential energy savings, smart meters, In-home displays, residential energy monitoring, energy feedback field experiments.

1. INTRODUCTION

Decarbonizing of the energy sector is crucial in mitigating the impact of climate change. To achieve this goal, there exist two main approaches: utilizing renewable energy sources; and reducing energy consumption. Renewable energy sources such as solar and wind power can play a major role in replacing fossil fuels, but they are intermittent in nature. Therefore, reducing energy consumption through energy efficient design and consumer behavior such as demand response has become a crucial component of the decarbonization effort. The building sector contributes to 30% of the world's total energy consumption, making it a major player in reducing energy consumption and promoting energy efficiency. Energy efficiency can be achieved through both design and consumer behavior, such as changes in operations that reduce energy consumption. For example, designing buildings with energy efficient features, such as tightly sealed thermal envelopes, controlled ventilation, or high-efficiency heating and cooling systems, can significantly reduce energy consumption. Additionally, implementing demand response and feedback programs that encourage consumers to reduce their energy consumption during peak periods can also play a significant role in reducing energy consumption.

In the context of energy monitoring and display systems, feedback refers to information provided to the consumer about their household energy consumption (Buchanan, 2014). Historically, feedback began for energy savings during the first energy crisis in 1973. The crisis inspired Dutch researchers to analyze their household energy consumption and recommend solutions to mitigate the challenges their country was facing. Unlike traditional installation, where the energy display meters were installed outside, they installed the energy display meters in the households' living rooms. They observed 30% less energy consumption than Amsterdam neighborhoods with similar household characteristics). Another research carried out in response to the energy crisis of winter 1973-74 (Seaver, 1976) reported that feedback with and without commendation had a differential impact on fuel conservation. When compared between the monetary payments, energy information (energy saving tips or advice), and daily feedback on energy consumption at the university student housing complex, it was observed that payments (incentives) led to immediate and significant consumption reduction in all units, even when the magnitude of payments was reduced substantially (Hayes, 1977). Another field study (Becker, 1978) showed a significant reduction in electricity consumption when feedback was presented in conjunction with goals to achieve. These findings suggest that the households' energy consumption behavior can be modulated when the energy consumption reports are made more accessible by arranging the feedback in households' living space (James, 2018), along with providing incentives (Hayes, 1977) and social appreciation (Seaver, 1976). Further, (Seligman, 1977) has observed that immediate feedback with social and monetary incentives would effectively change the individual household's response to energy consumption.

The intention behind providing feedback is to make energy consumption more visible to the users (Darby, 2006), (Hargreaves, 2010), (Buchanan, 2014) so that they know which appliance(s) is/are consuming more energy and can take appropriate measures to reduce the consumption. Feedback is supposed to be kept as simple (Schultz, P. W., 2015), (Mogles, N., 2017) as possible so that it is easily understandable by users. In the earlier days, feedback was kept as simple as possible so that it was easily understandable by the users. (Kohlenberg, 1976) found that feedback using a simple light bulb helped reduce peak consumption. The bulb illuminated when the current levels exceeded 90% of the peak levels recorded in the previous two weeks. Today, feedback has evolved from simple bulbs to smart IoT devices and gamification, which require user involvement. One such IOT device is energy feedback system, which is gaining widespread attention from technology, infrastructure, management, and data analytics point of view (Brambilla, 2017). In such cases, displaying feedback information alone is not sufficient. The devices should be able to provide more information through interactive design having user-centric interfaces. The expansion of IOT interfaces demands user-centered design to make the IOT devices more acceptable and accessible among users (Brambilla, 2017). However, (Pereira, 2019) observed that with time, participants lose interest and stop using the device. Considering feedback reinforcement learning theory (Schacter et al., 2009; Langrial, 2014; Vlaev and Dolan, 2015), it can be argued that immediate feedback (Seligman, 1977) with social and monetary incentives would effectively change the individual household's response to energy consumption.

In user-centered design, the user profile, experience, and their need play a critical role in development and evaluation process than the technological specification. Don Norman states, 'But user-centered design emphasizes that the purpose of the system is to serve the user, not to use a specific technology, not to be an elegant piece of programming. The needs of the users should dominate the design of the interface, and the needs of the interface should dominate the design of the rest of the system' (Norman, 1986, see Gulliksen et al., 2003). It becomes imperative that we need users' perspective at every stage of product development, starting from conception to development to testing phases. Any successful design principle, especially display design encompasses user-perspectives of presenting information using Gestalt principles of organization (Paay et al., 2007; Ripalda et al., 2020), sensory-motor contingencies (Beaudouin-Lafon, 2004), attention (Toreini et al., 2020), and memory or cognitive load (Feinberg and Murphy, 2000). For any effective and efficient display interface, it is recommended to avoid cluttered displays (e.g., less is more), reduce the gap between information display and the user's mental model, use metaphors or icons as per users' linguistic cultural ethnicity, minimize memory load (Reeves et al., 2004), maintain consistency at multiple levels (e.g., functional, visual, internal and external), and display feedback appropriately (Reeves et al., 2004).

There have been several reviews in the domain of residential energy feedback. The findings from field studies show that energy savings from energy feedback typically falls in the range of 5–20%, where the duration of the studies varied from 1 month to 2.5 years. Early reviews (Abrahamse, 2007); (Darby, 2006); (Fischer, 2008); (Ehrhardt, 2010); (Faruqui, 2010); (Roberts, 2003), (Zvingilaite, 2015), (Zangheri, 2019) show that different types of feedback tend to produce different results in energy savings. With the advancement in feedback technology, present studies (Chatzigeorgiou, 2021); (Chalal, 2022) focus on different design and visualization techniques of feedback. We have not found any reviews that have organized the different feedback types as a hierarchy and defined their association with energy savings and hence there is a need for such studies. In this paper, an attempt has been made to review studies that conducted on-field experiments and not those that were conducted in the lab through simulations. Our paper provides a comprehensive understanding of how energy studies are being conducted, how people have studied feedback, and measured savings. Due to a lack of consistency in the usage of terms for categorizing feedback, a taxonomy has been proposed based on feedback types. Further, energy savings from similar feedback types can differ depending on how the study was conducted. Therefore, we try to understand the different ways in which on-field studies are conducted and their relationship with energy savings.

2.METHODOLOGY

Several articles and journals related to home energy feedback were reviewed. A combination of terms 'home', 'residential', 'energy' and 'feedback' were used to search for relevant papers related to feedback studies between the years 1979 to 2021. Closely associated keywords such as 'house', 'household' and 'studies' were also used during the search. The reference list from the resulting papers offered further guidance relevant to the study. Scientific databases: Scopus, IEEE, ACM, Taylor & Francis Online, Springer, ScienceDirect. JSTOR and SAGE were explored for published literature related to energy feedback studies. The search resulted in review (survey) papers on feedback and papers on field studies. The review(survey) papers were used to understand how different researchers have characterized feedback. These papers helped in building the characterization hierarchy/taxonomy. Search results related to feedback studies that conducted on-field experiments were checked for and those that fit the field studies selection criteria alone were considered. There were 31 such papers that conducted field studies on residential energy feedback and helped us explain the different ways in which field studies are conducted.

The criteria for selecting papers related to field studies as shown in Figure 1 are as follows:

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.

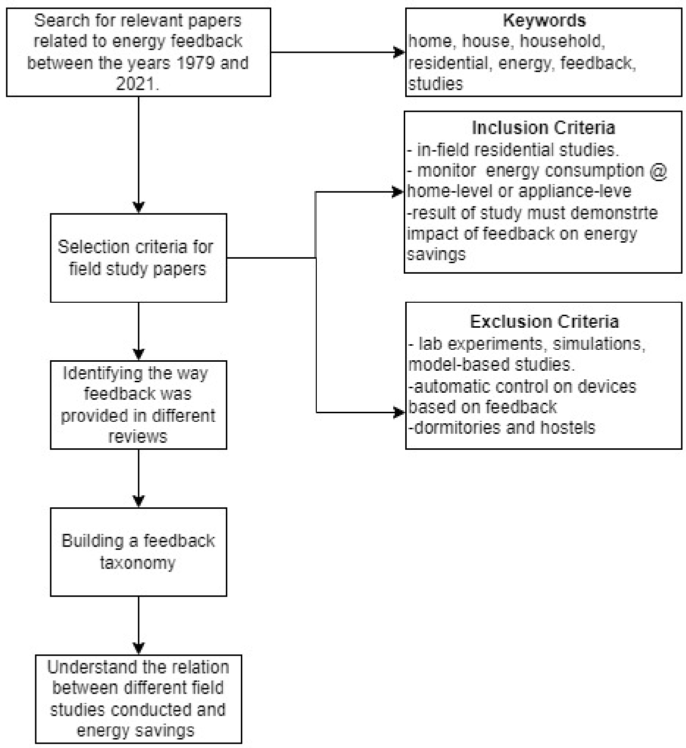

Figure 1: Flowchart representing the methodological process of this review.

The collected field study papers were categorized to build a classification hierarchy on feedback types. The methodology followed is:

1. Explore existing works to understand if there is any need for a new review paper.
2. Understand how different researchers have characterized the feedback system specific to residential field studies.
3. Applied the criteria for selecting papers related to field studies. Based on these studies and review papers, we have characterized the type of feedback studies.
4. Developed a typical feedback characteristic hierarchy.
5. Understand how energy savings relate with types of feedback studies.

3. OVERVIEW OF SELECTED FIELD STUDIES

Figure 2 shows the distribution of reviewed publications with their year of publication. The trend is increasing, and this decade should expect a good number of quality studies on energy feedback.

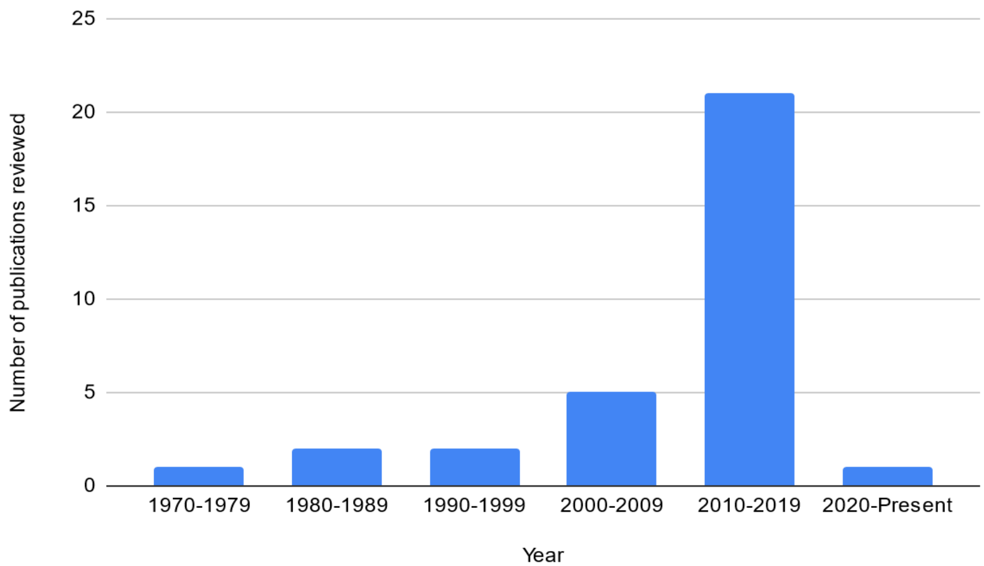

Figure 2: Distribution of reviewed publications, year-wise

Figure 3 illustrates a bibliometric map made with the help of VOSviewer (van Eck, 2010). The terms selected and map constructed is based on occurrence count of terms (statistically calculated and selected by VOSViewer) in the Title and Abstract of the review studies i.e., if more is the occurrence count for a term across papers, then more would be the weightage of that point/term.

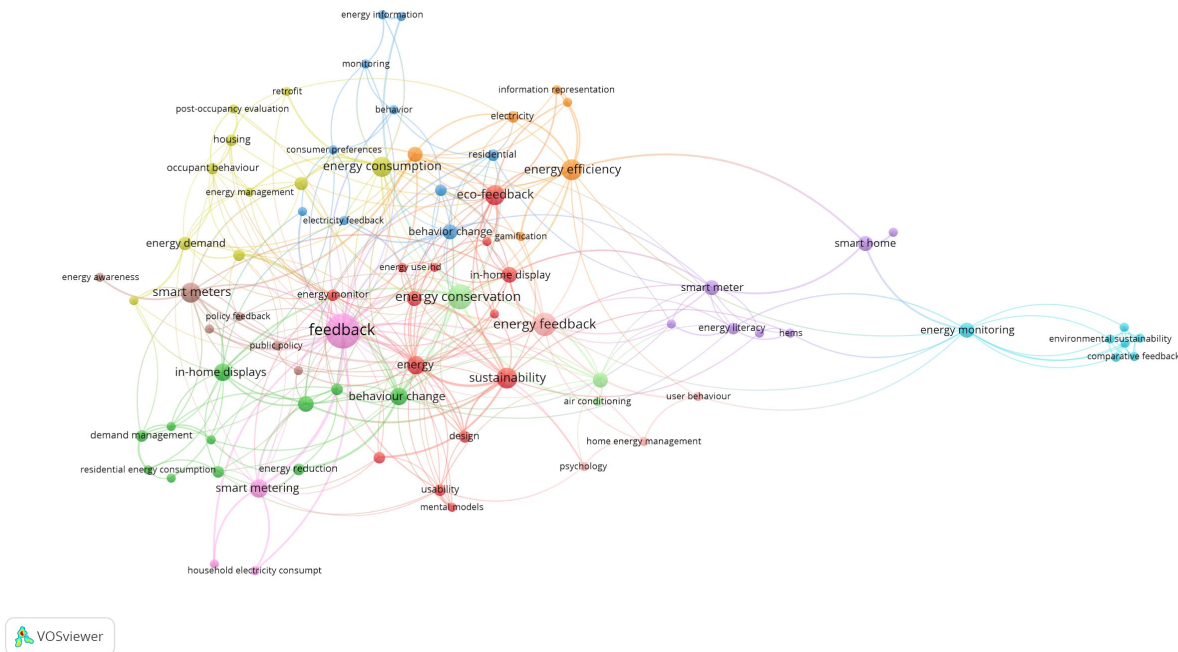

Figure 3: Word cloud of the key works being used

Observations from the word cloud show that “feedback” is the highest weighted point, followed by “smart meters”, “In-home displays (IHDs)", “energy conservation”, “behavior change”, and “sustainability”. This indicates the frequent use of these words in the reviewed publications, suggesting IHDs and smart meters are some of the key topics of discussion on residential energy feedback.

The selected field studies include those that were carried out in actual occupied households and not dormitories, hostels, or sample studies that were carried out as lab experiments. The studies selected include field experiments which have measured energy consumption and energy savings or peak load reduction through feedback intervention. These studies considered energy feedback for different types of energy such as electricity, gas, and transport that are mostly carried out in developed regions of the US, Europe, and Japan. Most of these are in cold climate zones with heating demand. The household types vary from detached houses, apartments, to identical rental houses. The feedback information provided includes energy consumption, energy cost, comparison with historic or past consumption and comparison with neighborhood. The duration of study ranges from as short as a month to 3 years. The feedback can be real-time, daily, weekly, or monthly. The size of the study varies from 10 homes to a hundred homes.

Summary of important aspects of the selected publications is provided in this table in the Appendix section.

4. 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 shows the taxonomy of characteristics of energy feedback.

At the top level the characteristics of feedback are classified as:

i. 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).
ii. 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.
iii. 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).
iv. 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.
v. 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).
vi. 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).

Each of these characteristics is further sub-classified and explained in detail.

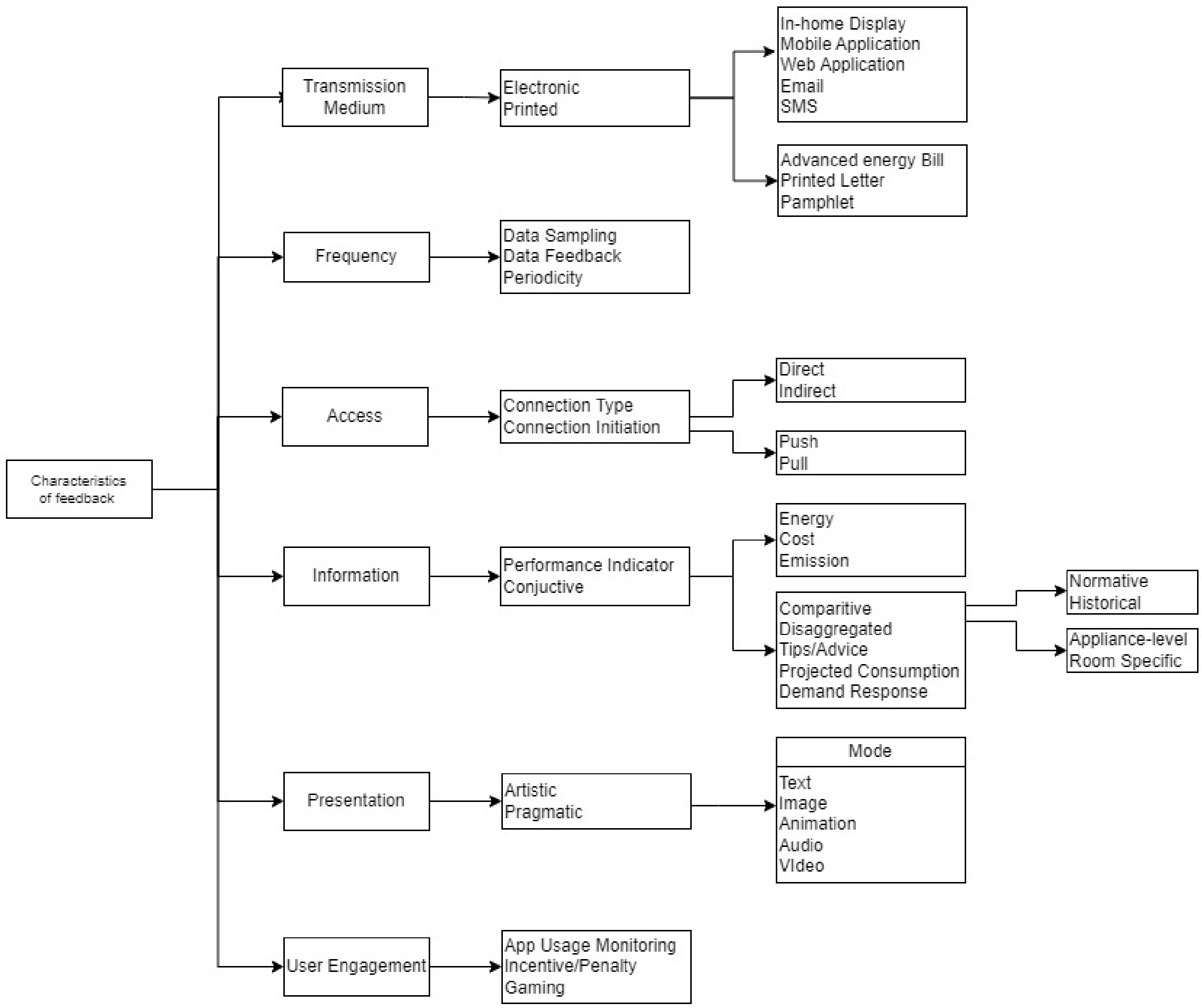

Figure 4: Classification of energy feedback

Based on Figure 4 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.

(Fischer, 2008) was one of the earliest reviews in which the term medium was used to classify feedback. (Fischer, 2008) sub-classified medium as electronic media and written material. The same was adapted by (Froehlich, 2009), (Froehlich, 2010), (Schleich, 2013)and (Kerr, 2012). (Zangheri, 2019) classified medium types as IHD, bill, mail, PC or web cards, and mixed modes (). Authors have used the term online to represent feedback via electronic medium. By such means medium can also be classified as online or offline. Different researchers have used terms such as online feedback system (Murugesan, 2017), online platform (Geelen, D., 2012), online energy tool (Spence, 2014), online services by energy utilities (Zvingilaite, 2015), when feedback is provided through IHD, web or mobile applications. However, this classification can be confusing because, the dictionary meaning of online is "controlled by or connected to a computer", which may or may not include feedback through electronic mediums of feedback such as smart meters, SMS, and emails.

Among the reviewed publications, a major number of studies used feedback through electronic medium. (Kerr, 2012) mentioned that paper-based bills were the preferred medium for many consumers and changing this to advanced paper bills that included detailed feedback can help make use of the already preferred written medium. (Gleerup, 2010) found that feedback through email and SMS messaging resulted in an average reduction of about 3% in the total annual electricity use. Though we have considered only residential studies in this review, an interesting finding was noticed in a study with dormitory setup; (Jain, 2015) observed that providing daily consumption paper sheets to the consumer is analogous to newspaper distribution. A productive solution for developing energy saving habits would be if these sheets are given along with the newspaper. The author also realized that using paper-based feedback is not a sustainable and green solution, and suggested computer and mobile based feedback to be explored more. An attempt was made by (D'Oca, 2014) to give web-based newsletters to the user in residential setup. Similarly, (Mogles, N., 2017) tried web based weekly digest on tablets and (Brandon, 1999) gave energy saving tips on leaflets.

Advancements in technology opened the possibility of designing frequent, informative, and interactive energy feedback systems of which IHDs have become a very popular medium. Many publications (Marchiori, 2012), (Westskog, 2015), (Xu, 2015), (Mogles, N., 2017), (Canale, 2021) suggested that the use of IHD ha resulted in good amount of energy savings. A recent study (Canale, 2021) mentioned an average of 12% reduction in electricity consumption due to the use of IHD. Figure 5 shows a distribution of the number of studies and the percentage savings* observed in the studies with and without In-Home-Displays.

*Several factors are responsible for energy savings in a study. We are not stating that the savings are due to the medium of feedback alone. The results are presented to understand the potential of savings due to the medium of feedback.

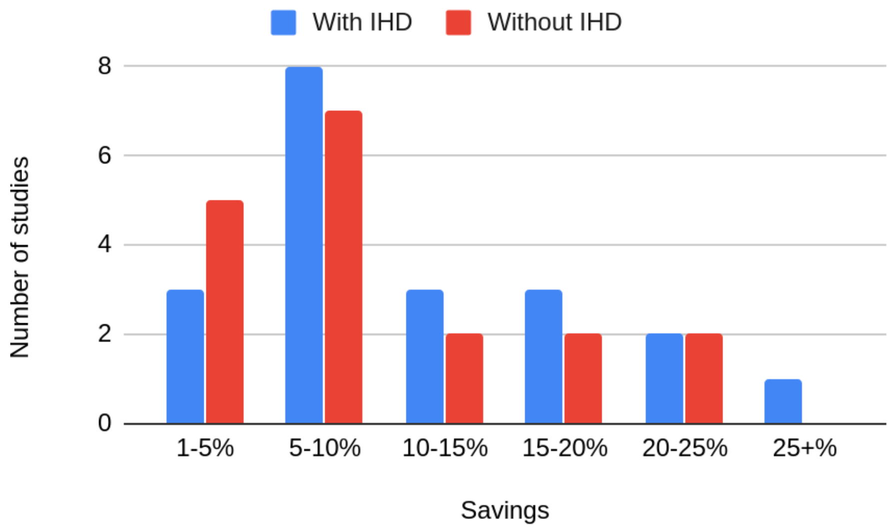

Figure 5: Energy savings comparison with and without IHD

IHDs have immense energy-saving potential and can display different types of feedback information. However, it has not been conclusive that IHDs are an ideal medium to provide feedback. It has been observed that households abandon (Bonino, 2012), (Anderson, 2009), (Murugesan, 2017), (Hargreaves, 2018), (Shafqat, 2019) IHDs and other smart energy devices after a few weeks/months of usage, due to lack of understanding, declining interest with time or other unmentioned personal reasons. These abandoned IHDs in worst-cases add to single-use plastics (Snow, S.,2019) which creates another environmental problem. (Murtagh, 2014) noticed that only 4 households (out of 21) continued to use IHD after 6 months of installation. To solve this problem researchers are exploring other alternatives of online feedback such as web applications, mobile applications or use of television screens. (Vassileva, I.,2013) for example used a TV channel to broadcast the last 7 days of energy consumption for each individual home in an apartment. They provided a channel that was created by the local digital TV provider.

The location of an IHD also plays an important role in energy savings. The location of a device within a home will affect how frequently it is viewed and by how many people (Kerr, 2012). A display located in the kitchen, living room or any active part of the house will be more easily accessible to the consumers and would help keep a better track of energy consumption. Feedback through displays on smart appliances or through mobile apps can further localize it by making information easily accessible.

In a questionnaire-based survey, (Bonino, 2012) asked nearly 1000 participants through online survey, their preferred IHD location at home. The majority (32.66%) of participants preferred the kitchen, followed by lobby/corridor (20.44%). The third preference was the “most popular room” (13.36%). Few studies show that placing energy consumption feedback devices near the appliance source (localized displays) is also a promising direction. (McCalley, 2002) gave consumers immediate feedback about washing machine energy usage via an attached control panel and found a 21% reduction in energy use. (Immediate feedback was found to be effective as in (MCCallley) study)

About 10 of 31 studies use IHD as a medium of conveying feedback. Other mediums such asweb based feedback, and displaying on laptop screens are also popular.

FrequencyFrequency 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 monthly bill for overall energy consumption (daily feedback frequency) on the and in that getting weekly/daily data is feedback resolution.

Feedback frequency was discussed by (Fischer, 2008), (Froehlich, 2009), and (Kerr, 2012). In the reviewed studies, (Fischer, 2008) found that feedback frequencies can be continuous, daily bimonthly or monthly. Feedback frequency can be real-time or delayed, it is also a measure of the latency in the reception of energy feedback. Real-time feedback (Ehrhardt, 2010), (Karlin, 2014) is the one in which data is processed within milliseconds and the information is available as feedback instantaneously or whenever the event occurs. When the information is updated any time later then it is called delayed feedback. There can be sub classifications under delayed feedback: *low delay* when data is updated in less than a day, *medium delay* if it is updated between a day and a month, and *high delay* if it's updated after a month.

According to (Fischer, 2008). immediate feedback leads to quick user actions and delayed feedback leads to new habit formation .(Froehlich, 2009) and (Kerr, 2012) found that frequently updated feedback systems help in reducing electricity consumption. (Kerr, 2012) pointed out the need to check if frequency should vary across different seasons, because of the variation in energy consumption .

(Froehlich, 2009), used the term data granularity in terms of *time* (e.g., data can be viewed at different temporal resolutions i.e., amount of consumption per day, per month, per year), *space* (e.g., specific rooms, upstairs vs. downstairs), *specific source* (e.g., refrigerator, washing machine, upstairs shower), or *source category* (e.g., kitchen appliances, lights, bathrooms). The resolution of feedback information provided in *time* i.e., daily/monthly, or weekly is mentioned under *Statistics* in the information section. The breakdown of information in terms of spatial and source is covered in the enhanced information classification section (disaggregated information). (Schleich, 2012) delivered feedback which displayed hourly, daily, and monthly data on a web portal and displayed monthly feedback on a printed medium.

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.

The reviewed studies are dominated by those providing real time feedback. About 14 studies are seen to be providing feedback in real time, 3 provide feedback weekly and 4 studies provide monthly feedback.

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.

(Darby, 2006) observed from literature that instantaneous direct feedback in combination with frequent, accurate billing (a form of indirect feedback) is needed as a basis for sustained demand reduction. Both types of feedback have their own advantages and disadvantages and a well-designed combination of both could be an ideal approach for good feedback.

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, forecast, demand response, and statistics.

(Zangheri, 2019) classified the type of information as real-time, appliance disaggregation, social comparison, historical comparison of energy consumption, energy consumption rewards and energy efficiency advice.

As per (Bertoldi, 2016) typical energy bills provide the cost of energy consumed for a specific time period. Such information is very basic and does not give sufficient understanding of the action users can take to save energy or reduce their household consumption. Thus, to make the feedback engaging for the users this information can be enhanced by presenting it as disaggregated feedback, comparison with neighbors, comparison with past data or tips/advice (Gangale, 2013) (Hargreaves, 2018) (Iweka, 2019), (Backhaus, 2011). As per (Gangale, 2013) information is engaging if it motivates and empowers the consumers to become active (conscious/aware) energy customers. Several attempts (Nilsson, 2018), (Podgornik, 2016), (Schultz, P. W., 2015) have been made by researchers to display energy consumption information in a more innovative and understandable manner thereby engaging the users. (Gangale, 2013) suggests that to engage the users, information about energy consumption and newly introduced smart technologies/appliances must be provided, along with that the feedback should have strategies aimed at behavioral change.

Summarizing findings from the reviewed studies, 15 interventions give cost interventions, 11 provide historic energy consumption, 5 show appliance wise energy consumption disaggregation and 12 give energy saving tips. The interventions are sub parts of the complete study, each study may have more than one intervention.

Performance Indicator

Performance Indicator refers to the single or multiple data points that present essential information, such as energy units in kWh, energy cost and carbon emission.

As classified in (Fischer, 2008) and (Froehlich, 2009), energy consumption in simple terms can be displayed in the form of energy, cost or emission. (Fischer, 2008) named this classification as "content" which included consumption in terms of kWh, cost, or environmental impacts. (Froehlich, 2009) classified the same as "Measurement unit" and was later adapted by (Kerr, 2012) and named "Unit of Measurement".

In terms of energy, the consumption is usually displayed in terms of kWh units which is very common and widely used. However, understanding feedback in terms of kWh can be confusing for users when trying to make inferences from the feedback information. It was observed by (Kjeldskov, 2012) that the unit of energy (kWh) was poorly understood by participants, due to which they were unable to change their behavior for saving energy. Further, energy can be presented in terms of equivalent cost and emissions. CO_2 emissions are released when a certain amount of energy is consumed (Podgornik, 2016). (Berry, 2017) converted energy consumption to associated greenhouse gas emissions and the users stated that the information was found confusing. (Podgornik, 2016) presented a CO_2 indicator relative to the number of trees needed to compensate for the CO_2 produced per household. It was assumed that the average yearly CO_2 absorption is around 10 kg CO_2 per tree.

(Rettie, 2014) suggested that emphasis should be given to provide feedback in terms of activities rather than energy units (money, kWh, kg of carbon dioxide) to enable better engagement with the users. This can be done in relatable terms such as showing the equivalent number of car or flight trips (Froehlich, 2009), (Kerr, 2012).

Thus, information is presented by many authors in terms of various units such as money, kWh, kg of carbon dioxide. While information presented through performance indicators are easy to understand and communicate and can also relate to environmental parameters or relatable parameters such as number of car trips, 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. Hence, there is a need felt by many researchers to provide this information.

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.

a. Comparative

To make the feedback more informative and useful, comparison with the past consumption data is displayed to show energy savings (Ueno, 2006), (D'Oca, 2014), (Ueno, 2003). In addition, comparison can also be made with the consumption of peers/neighbors, to give users' a competitive view of their consumption. An experiment conducted by (Schultz, P. W., 2015) compared the energy savings achieved by giving feedback to three different groups providing them with information on energy consumed, cost and normative feedback (social/peer group comparison). Significant savings were achieved by providing normative feedback which demonstrates that normative feedback can be an effective tool to promote residential electricity conservation. In a meta study (Kjeldskov, 2012) mentioned there is a need for communicating the amount of electricity consumed by combining absolute measurements (e.g., current week's energy consumption in kWh) with comparative visualization (such as comparison with previous week or comparison with other households), allowing consumers to determine and analyze their consumption. It was found that people appreciated an abstract representation of the electricity consumed e.g., an evaluation of consumption as low, medium, or high in comparison with other households. The visualization of comparative usage was found to be useful for households with both limited and high awareness of electricity usage. (Delmas, 2013) found that strategies providing individualized audits and consulting are comparatively more effective for conservation behavior than strategies that provide historical, peer comparison energy feedback.

b. Disaggregation

Disaggregation represents the breakdown of information especially at the appliance level or spatial level. However, in literature, disaggregation has been interchangeably used with data granularity. (Froehlich, 2009); (Kerr, 2012) say feedback can further be detailed by adding disaggregated information to it, this is referred to as data granularity We have used the term disaggregated here since it clearly indicates unbundling of information at appliance level or room level over data granularity which seems to convey the resolution of the data (we have referred to resolution of data in statistics section of information).

Disaggregated information can be very useful in tracking which appliance or room of the house is consuming more energy. (Kendel, 2017) provided appliance specific feedback on up to two appliances, which users could choose. (D'Oca, 2014) gave smart plugs to monitor and implement on/off features for up to five appliances. (Ueno, 2003) displayed disaggregated power consumption of up to 16 different appliances and compared daily power consumption of the living room and other rooms. (Truong, 2017) proposed Building Information Model (BIM) integrated energy visualization approach to allow users to visualize energy consumption of each room through a color-coding scheme. Identifying appliances that consume high energy in a household gives the scope of replacing them with higher efficient appliances or reducing their usage. On the other hand knowing the high energy consuming room is not that useful as it doesn't provide any information which helps in taking energy saving actions. (Bonino, 2012) found room level feedback proved to be interesting for the participants. However, in some rooms such as the living room, the energy consumption was more than others, thus these rooms were always shown in red color. It was suggested that the goals for room-level consumption should be set by the participants to make the information more actionable.

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.

Forecast

Forecast 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. (Krishnamurti, 2013) found that participants ranked daily projected/forecasted consumption at third place after energy bills and appliance specific feedback. Monthly projected consumption was ranked fourth. Projected consumption can motivate users to reduce their current consumption. (Sexton, 1987) presented projected monthly bills and whenever it exceeded the budgeted bill, the information display would blink a warning signal. (Iwasaki, S.,

2019) displayed the projected impact of the energy saving action taken by the participants in terms of CO_2 emission reductions. 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.

Statistics

Statistics comprise the spread of data (e.g., mean, or median) in the context of varying units of time (e.g., daily, or monthly) while using basic visualization techniques (e.g., chart). Previous research shows (Arvola, 1993); (Ueno, 2003) that energy feedback employs descriptive statistics and visualization to report the pattern of households' energy consumption. For example, for weekly feedback (determined by the feedback frequency) the user may have the data spread of daily average energy consumption or daily variance of energy consumption, and this data can be presented in text or bar chart. The data resolution or granularity at which the feedback information is presented to the user. This information can give the user some extra information about their consumption pattern.

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.

An example of peak load shifting analysis was shown by (Kendel, 2017), where two groups were provided with energy feedback, one was given aggregated consumption and the other was provided with disaggregated consumption. It was noticed that off-peak load shifting was practiced more in the group with appliance level disaggregated feedback. It was also realized that loss of interest among consumers is a major issue with IHDs, due to which they might not be a good long-term solution for demand side management. (James, 2013) designed time of use tariffs by increasing peak load pricing for the trial group while the control group was charged at their usual price. The charges were balanced such that the amount of increase in peak cost was balanced with off-peak savings, to keep the average household's electricity cost unchanged. An average 8.2% reduction in peak energy consumption was noticed in all demand side management groups having varying time of use tariffs.

To summarize, information from the grid involving response messages might not necessarily help in lowering the total energy consumption but might help in reducing the total consumption cost and overall energy generation load on the grid.

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).

Infographics constitute graphical data and artistic elements (Lu et al., 2020) aiming to present complex information and data in a way that is easy to understand. An effective infographic can stand on its own as a separate piece of content, in other words the whole information is contained in one image. Often, pieces of information are organized into visual groups, which are compound graphical data elements for multi-facet information, e.g., an icon, a subtitle, or a textbox. It has been observed in the literature (Nilsson, 2018); (Romano, 2019) that mobile application screens and dashboards that are designed to display information related to energy feedback double as infographics.

Text-based feedback is easy to understand and conveys less information, while graphical feedback can show trends and comparison over time and is more informative. Using charts, graphs and technical units to display information can sometimes be difficult to comprehend (Francisco, 2018), (Bonino, 2012), (Rodgers, 2011). As per cognitive load theory, displaying a lot of information might help improve knowledge but makes the display more congested and might lead to users losing interest in looking at the display (Kathryn, 2013). In early studies, due to limited availability of technological resources, (Winett, R. A., 1979) provided feedback through paper and (McClelland, L., 1979) through light-emitting diodes on a panel for a continuous display. It is interesting to note that even after providing a very simple text-based feedback through a continuous display, McClelland, L., (1979) observed a 12% average reduction in electricity consumption and (Winett, R. A., 1979) reported 13% savings in a group of householders who received daily written feedback on their electricity consumption. (Schultz, P. W., 2015) and (Mogles, N., 2017) provided simple text-based feedback through an IHD, perhaps conveying that simple text based feedback is an important or popular feedback information and can enable energy conservation merely by using an IHD along with a traditional printed bill.

Several studies (Winett, 1982), (Haakana, M.,1997), (Fell, 2014), (Schultz, P. W., 2015), (Pereira, 2020) used videos to help users understand features of the interface, home energy monitoring system or to enhance energy literacy by teaching how users' could save energy. (Haakana, M.,1997) prepared advisory material in the form of a video and literature. It included details of different brands of HVAC systems, adjustment devices available for households, and the technical equipment (appliances) used for feedback. It was found that video-based advisory material made the appliances easy to understand. The advisory material was rated as "good or quite good" by most of the households and around 13% of the households altered their habits because of the feedback material. (Schultz, P. W., 2015) displayed a short 2-min animated video to describe the ecological effects of electricity consumption on the San Diego region. It was found that there was no significant change in energy consumption between households that watched the video and those who did not. There are many factors such as content of the video and duration of the video which can impact energy savings from feedback through videos. Using videos for feedback may not directly lead to energy savings but might help in increasing technical knowledge (understanding of the feedback system) and energy literacy which can indirectly lead to energy savings in the long term. It is seen that videos mostly are used for the purpose of providing operational information for various devices or as an education tool and rarely for providing energy feedback.

Although many feedback notification systems involve the use of audio such as the alarm system used by (Stinson, 2015) , we could not find publications with only audio-based energy feedback. It would be interesting to see the impact of such feedback type on savings and user behavior.

To make the interface more interactive and help the consumers to better understand their household consumption, different types of indicators have been used. These indicators are something which people use or see in their daily lives such as speedometer, traffic light or emoji . (Nilsson, 2018) used a speedometer like display to show energy consumption, (Stinson, 2015) used green, amber and red colors similar to traffic lights to denote levels of energy consumption. (Vassileva, I.,2013) and (Young., 2013) used emojis to indicate energy consumption performance of users' homes. (Vassileva, I.,2013) provided a special TV-channel created by the local digital TV provider which displayed real time and past 7 days electricity consumption information of individual apartments.

(Young., 2013) provided feedback to users by saying “great, good, or more than average” to tell users how well they are performing. Acknowledging people about their performance might be a good technique to engage people in energy saving activities.

According to Herrmann (2021), energy data visualizations can be enhanced by enabling users to manipulate and annotate their data, which can lead to reflections on energy usage and facilitate insights into reducing consumption.

When people start relating energy consumption with indicators used in day-to-day life, this makes it easier for them to understand their household energy consumption and it can lead to more frequent viewing of feedback interface and taking necessary actions to save energy.

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.

Most of the reviewed studies had feedback with one-way interaction i.e., sending information relevant for energy saving to the user. In response to every energy saving advice (Ueno, 2003) attempted to understand users’ response to the advice, by asking them to respond by pressing one of the following three response buttons: [Yes], [I will try] and [Neither]. Bi-directional feedback is not much used in research yet, but it is a good way to record consumers' participation in the trial. Knowing what kind of action, a consumer is willing to take might help in giving feedback focused more on such actions and knowing what users are not liking might help improve that part of feedback. (Pereira, 2019) monitored the number of mouse clicks and screen touches and found that with time participants were losing interest and stopped using the device. (Canale, 2021) also recorded occupants' interaction with the IHD by counting the number of clicks on the screen. It was noticed that 60% of the participants clicked on the IHDs less than 5 times per week on average during the trial, 35% clicked on the IHDs between 5 and 20 times per week, while 5% of them exceeded 20 clicks per week.

(Geelen, 2012) tried to make use of the competitive nature of humans by introducing gaming in feedback to save energy. An energy battle game was developed in which users competed with the participating households on their energy consumption. In the game credits were awarded to the teams (householders) with more energy savings, with these credits they can buy virtual building blocks which can be used to build a construction to win the game. Taking designs from the householders is a good way of indirectly monitoring their activity on the display or to track if they are taking actions towards energy savings or not. It can be noticed that adding gamification in energy feedback has a potential of increasing energy savings but there are very few residential field studies to prove this.

Incentives and penalties play an important role in changing habits and motivating participants to save energy and enable participation in demand response. In studies we found some of the incentives to be higher than the benefit accrued to the utility by the user's energy saving actions. We feel that such incentives are applicable only during the study and are aimed at understanding the maximum potential of energy savings. These incentives may not be possible in the real world. In the real-world utilities may provide incentives that are economically/financially viable. (Geelen, D., 2012) gave €750 worth kitchen appliances as prize to the team who saved energy the most and €250 worth dining vouchers to the most creative game construction. A rebate of $50 was given by (Snow, S.,2019), making the service effectively free for the households. (Nilsson, 2014) offered up to 150 SEK per month refund to the households with low electricity consumption, while households with higher consumption paid up to 600 SEK extra per month along with the rent as a penalty. The incentives that are given to participate in the study which are not linked to the performance are considered as a part of the study parameters.

In most of the studies, the penalty may not have been studied clearly. This is because in these studies participants who are voluntary members may not accept the penalty, which is very different from a real-world scenario. It can be said that there are very few studies which have robustly shown the implications of deploying a penalty as a mechanism to save energy.

5. DISCUSSION

In the previous section various characteristics of feedback were discussed. It was 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 experiment type (Randomized Control Trial, Longitudinal studies).

In this section we attempt 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

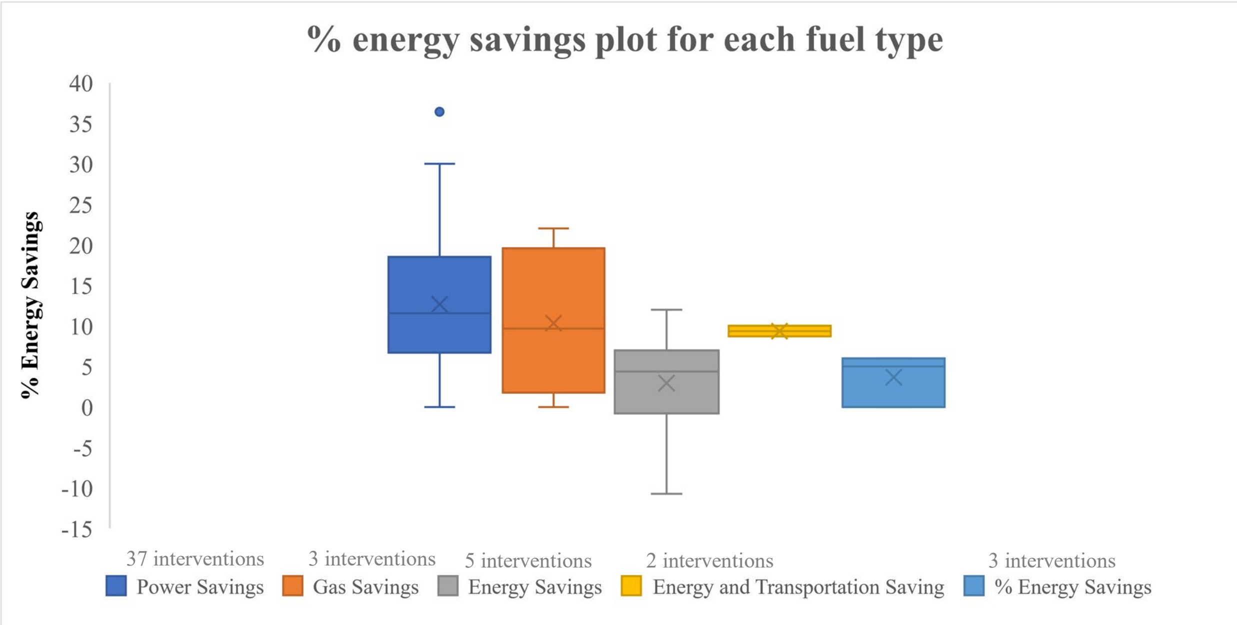

Figure 6: Percentage energy savings achieved for different fuel types along with number of interventions.

Field studies in Figure 6 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 31 studies that are reviewed in this paper. Most studies conducted feedback interventions aiming to reduce electricity consumption.

Savings - Depending on the Experiment Type

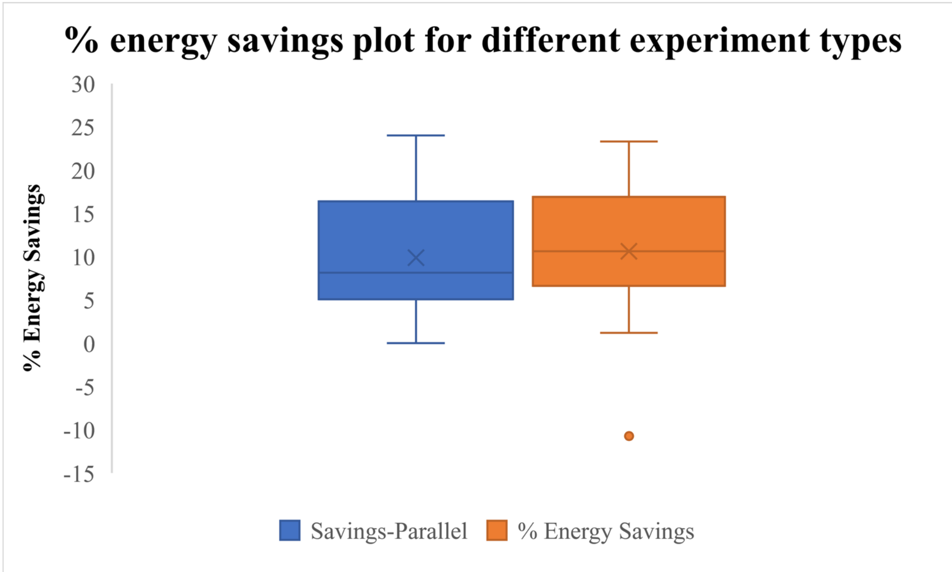

Figure 7: Percentage energy savings for different Experiment types.

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 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 7 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.

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.

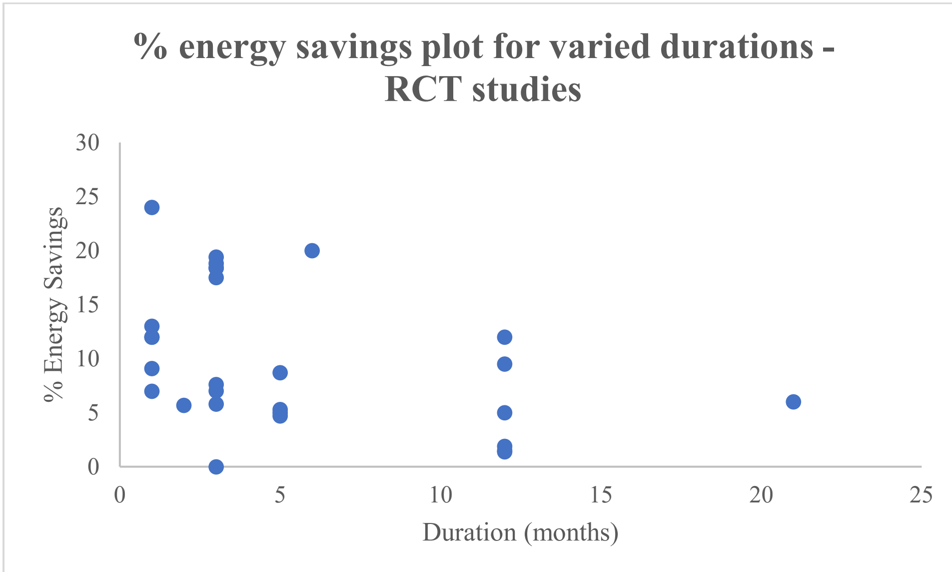

Figure 8: Percentage energy savings for RCT studies with varied durations.

In Randomized Control Trial studies, as seen in Figure 8, 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 nt being translated to real time learning.

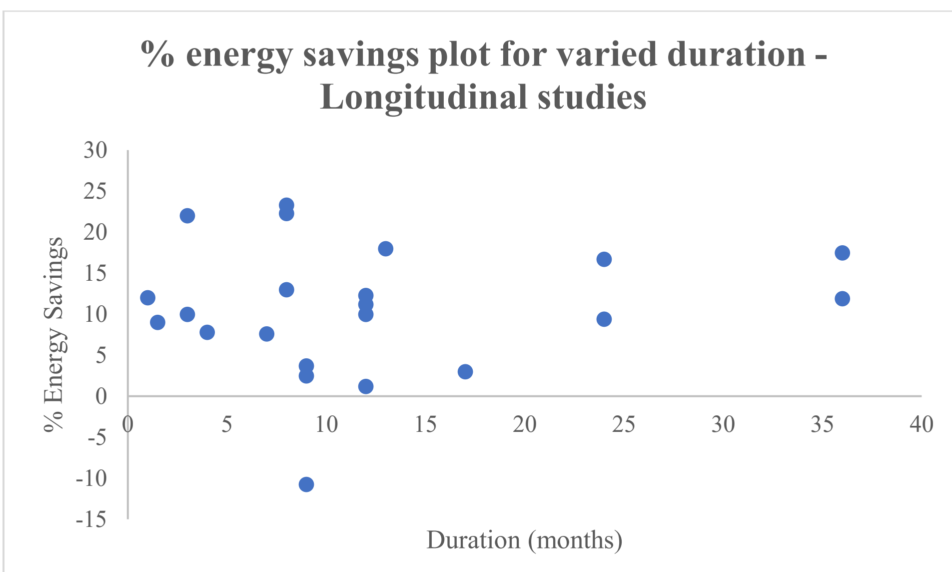

Figure 9: Percentage energy savings plot for varied duration of Longitudinal studies.

As seen in Figure 9 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.

Savings - Depending on the **Experiment Size**

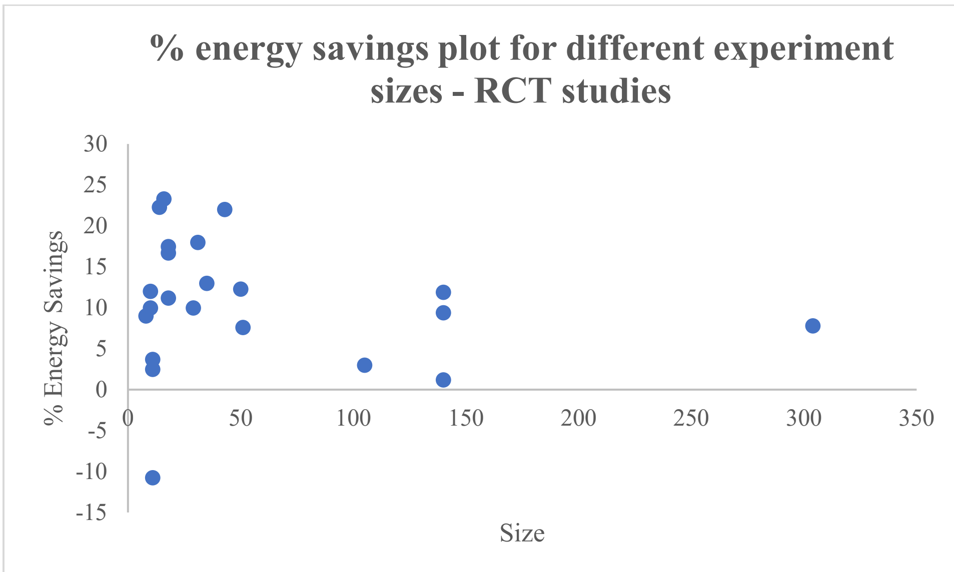

Figure 10: Percentage energy savings for different experiment sizes of RCT studies.

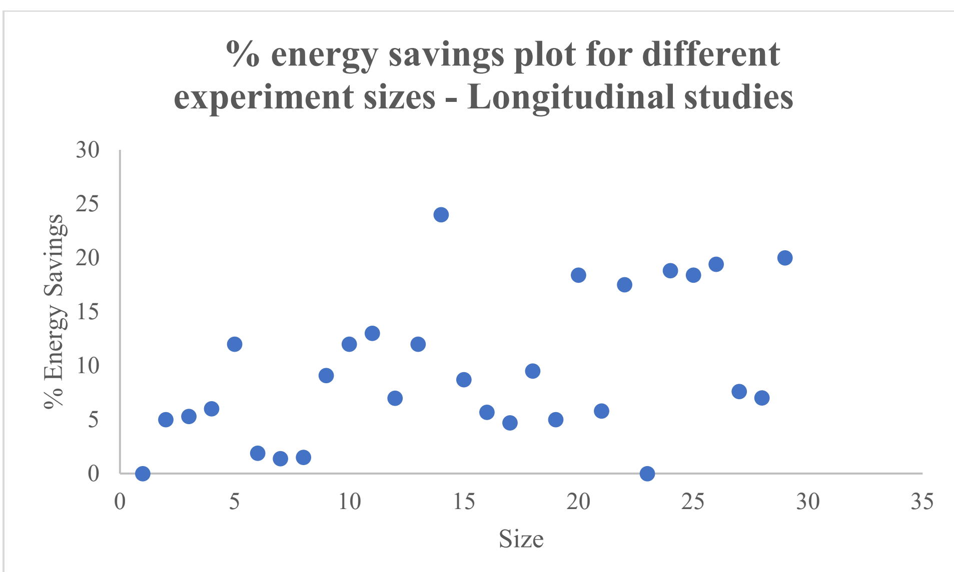

Figure 11: Percentage energy savings for different experiment sizes of Longitudinal studies

As seen in Figure 10 and 11, 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.

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.

6. RECOMMENDATION

Currently, 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 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 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).

7. CONCLUSION

We have reviewed several 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 1year). 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.

8. APPENDIX

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	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

		experiment in Helsinki												
5	Haakana, M.,1997	The Effect of Feedback and Focused Advice on Household Energy Consumption	Heat, electricit y, and water consum ption	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	Electricit y	Omaha	*Detail not available	1. Electricity consumption 2. Equivalent cost 3. Comparison with historic 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	Electricit y, 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	Electricit y, 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	Electricit y, 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:	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

						6. Comparison with neighbors								
10	Abrahamse, 2007	The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents	Electricit y, Gas	Groninger, Netherlands	73% Homeowner s	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	Electricit y	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	Electricit y	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	Electricit y	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	Electricit y	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	Electricit y	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

		energy management												
16	Vassileva, 2012	The impact of consumers' feedback preferences on domestic electricity consumption	Electricit y	Sweden	Apartment and private houses	1. Energy consumption 2. Comparison with historic 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 (EnergiKolle n)	Longitudinal	15
17	Houde, 2013	Real-time Feedback and Electricity Consumption: A Field Experiment Assessing the Potential for Savings and Persistence	Electricit y	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 experime nt)	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	Electricit y	Sweden	Apartments	1. Hot water consumption 2. Comparison with neighbors 3. Comparison with historic data 4. Electicity 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	Electricit y	Ireland	*Detail not available	Energy usage statement: 1. Electricity consumption 2. Comparison with historic data 3. Comparison with other customers 4. Advice/ tips IHD 5. Cost and tarrif 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 observations 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 historic 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	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

		Shanghai, China												
25	Stinson, 2015	Visualizing energy use for smart homes and informed users	Electricit y, Gas	Scotland, UK	Group A: Flats Group B: Semidetach ed 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	Electricit y	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?	Electricit y, 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	Electricit y	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	Electricit y	Sweden	Study 1: Separate or semidetach ed 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	Electricit y	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	Electricit y, 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	Electricit y	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	Electricit y	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 tabled)	Longitudinal	12.8

9. Declaration of competing interests

The authors declare that they have no competing interests.

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