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FCN Project Study

Subannual Billing Information for Heating and Water Costs

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Executive summary

When communicating with consumers, the most important objective is to "keep it simple". The mailbox is full every day, the phone keeps on beeping – and the messages are all too often unpleasant or at least annoying. In this world of information overload, in order to get information across, it needs to be delivered as concisely and intuitively as possible.

Among other measures, the need for consumer feedback has recently been increased by the Energy Efficiency Directive 2012/27/EC, passed in October 2012. It sets a framework for the EU member states to achieve a 20% increase in energy efficiency. Apart from requirements for installing individual meters wherever feasible, it ensures that all consumers receive accurate metering data and that billing is based on the actual (individual) consumption.

With the goal of motivating consumers to adopt more energy-saving or energy-efficient behavior, it has to be evaluated how the current (consumption-based) billing method for heating and water costs can be augmented with additional information and which kind of feedback leads to an increased awareness on the part of the user. The effectiveness of such measures has been proven to help exploit a substantial energy-savings potential (cf. tabular overview of achieved savings on p. 6/7)

An influential parameter in this endeavor is the content of the presented information. The most important distinction can be made between billing and consumption information. Individual, consumption-based billing has already been proven to lead to remarkable energy savings. To further enhance these savings, subannual consumption information can additionally be provided. The advantage thereof is that it can be delivered in the most suitable frequency, which can be determined by the provider in accordance with the users' needs and specific circumstances. Most existing studies have shown that more frequent feedback leads to higher savings in energy consumption (in the order of 7-12%).

For delivering feedback, different media can be applied. Besides the present billing and information system in use, which is a paper-printed letter, there is a broader range of possible feedback mechanisms like feedback delivered by a website, by smartphone or by in-home displays giving consumer-specified feedback about the energy use. While differing in technical complexity and possibilities for interaction, they are also suited at providing feedback in different frequencies. Due to the properties of heat and hot water, a moderate frequency of feedback every one to three months seems appropriate. This frequency challenges the economic viability of in-house displays. Paper-based or electronic mailings as well as internet portals or smartphone-based deliveries may or may not be more cost-effective.

When giving feedback, it is crucial that information about the amount of energy consumed is complemented with further details. These can be application-specific consumption data, a comparison with historical figures, or the (change of) consumption over time. The closer such feedback is to actual consumption, the more immediate and better tractable the reaction can be. Besides the more detailed consumption information, an incentive for energy savings can be the presentation of the consumed energy in terms of costs. A broad range of studies highlights the effectiveness of the ability for the user to set his or her personal energy conservation goals and being able to get sufficient feedback to follow up and evaluate the constant energy conservation process.

Besides frequency and contents of the feedback, the visualization of the information is an important factor impacting the successful transmission of the intended data. Thereby, colored and graphical illustrations help to catch the consumer's attention and make complex contents easily understandable at a single glance. This reduces the required effort on the side of the consumer and increases his/her involvement in the subject matter, supporting the desired behavioral adjustments towards energy conservation.

Further features, such as the environmental effects of energy consumption or the comparison with other households, also show high energy-saving results. A bill supplemented with recommendations on how the behavior could be changed can help consumers to identify further saving potentials and thereby positively influence the achieved energy savings.

In order to foster permanent savings, feedback should support 'intrinsic' behavior controls, such that consumers perceive energy saving as their own personal interest. This leads them to develop new routines and habits concerning their energy behavior or to invest in energy-efficient appliances or insulation. A majority of studies confirms long-term effects that often even increase over time as more and more knowledge about energy-saving behavior is acquired.

Behavioral change can take various forms that differ in effort in terms of time and investment costs. A low-effort, but highly frequent habitual change would be adjusting the heating habits, whereas an example for an infrequent, singular change would be reprogramming the thermostat. It is also possible to differ between high and low cost changes, such as simply changing certain habits or purchasing new appliances. If trying to achieve a change in behavior, the different possibilities and consumer profiles with their individualized preferences must be taken into account. Moreover, certain feedback measures tend to trigger different changes in behavior. The enhanced billing, for example, often leads to behavioral energy-saving changes, whereas real-time feedback tends to provoke investments in energy-efficient appliances.

The evaluation of the sample feedback form has shown that it is suitable for heating and hot water consumers. Since the literature suggests that the *medium* is not very influential on user behavior, the mailing system can be justified due to its cost-effectiveness. The chosen *frequency* of the sample is quarterly, and while the literature does not provide a clear conclusion here, it is reasonable considering the postal delivery. Historical and normative comparisons throughout the sample help the user to better understand the magnitude of consumption, while enabling to track changes over time. This is supported by colored *charts* and tables as well as action hints for immediate implementation.

Table: Summary of literature review

Study	Savings	Explanation of observed savings	Focus	Commodity	Country	p.
Abrahamse et al. (2005)	12%	No general trend for different frequencies	Review of several pilot studies, effects of feedback in different frequency categories	general (mainly electricity and gas)	Netherlands	20
IWU (2011)	14%	Monthly updates in online portal	Electronic data management	heating, warm water	Germany	14
Haakana et al. (1997)	3-9%	Households had to send in their own meter readings monthly; higher savings when supplied with additional information (most effective as video message)	Single family homes	district heating	Finland	19
Darby (2001)	5-20%	5% by direct feedback, adding information, interactive displays, and device-specific feedback increased saving rate to up to 20%	Grouping of 34 studies into "direct feedback" and "indirect feedback"	general (mainly electricity)	Nordic countries	20
Stern (1992)	10-20%	10 % for feedback, 20 % when complemented with advice	Change in communication can already lead to energy savings of about …	general (mainly electricity)	USA	25

Nielsen (1993)	7-10%	Applied a list of measures incl. individual consultancy and a raise in the tariff → lower savings when the last two are not applied	Test of enhanced billing for a period of 3 years	Single Family Houses, electricity savings	Denmark	34
Wilhite and Ling (1995)	7.6-10%	7.6% after year 2; 10% after year 3	Test of enhanced billing for a period of 3 years → enhanced billing obligatory since 1999!	electricity	Norway	35
Staats et al. (2004)	4.8-7.6%	Improving over time	Daily and weekly feedback was studied for the duration of three years	garbage, gas, electricity, water, transportation	Netherlands	35
Siems (2009)	6.5%		Examined the effect of real-time feedback	electricity	USA	33, 35, 39

1 Introduction

Energy efficiency has been identified in the EU policy-making as the most cost-efficient way of reducing greenhouse gas emissions that simultaneously contributes to the security of energy supply. Given the positive attributes and positive externalities associated with energy efficiency, academics, policy-makers and practitioners alike are striving to find cost-efficient and effective means to increase the efficiency of energy end-use. At the residential level, information provision in different forms has been identified as a key component in harnessing the energy efficiency potentials, especially in buildings. Enhancing the quality and frequency of energy consumption information in residential buildings is therefore one important policy area in the recently approved energy efficiency directive (2012/27/EC).

This study explores the scientific evidence of the effectiveness and design of feedback systems in energy consumption communication and billing. The aim is to provide a conclusive view of the nature of interaction between consumers and feedback systems, and of the design parameters in establishing effective feedback systems aiming at achieving energy savings. In particular, the study examines what kind of, and how frequent communication would be optimal to induce behavioral changes.

The research questions posed are the following:

1. Which type of communication is particularly well suited for inducing behavioral change amongst final consumers?
2. What is the optimal frequency and what is the optimal granularity of consumption and billing information?
3. Which additional information can support behavioral change most, and which kind of change is achieved?
4. Is there any difference between consumption information and (additionally provided) cost information?
5. How large are the achievable saving effects (short term, long term) by user and real property category?
6. Are these saving effects achieved by only a few or a broad mass of people?
7. Which barriers have to be considered regarding acceptance of final consumers?

In order to set the stage and to tackle these research questions, the report is structured as follows:

Section 2 gives a short introduction to the EU-level energy policy that aims at increasing energy efficiency in the residential sector.

In Section 3, the design dimensions of a feedback system are decomposed and analyzed. The theory of information feedback provides the foundation for the analyses. A review of several international studies and field trials in the energy sector provide empirical evidence of a wide range of feedback systems and of their effect on energy consumption behavior. Through the exhaustive literature review, the decomposed components of the design of information communication are presented and analyzed.

Section 4 brings the energy consumer to the center: consumer behavior and preferences, as well as population heterogeneity are examined in the energy consumption context.

Section 5 evaluates the feedback sample in more detail and gives recommendations for possible improvements.

The report is concluded with Section 6, including a discussion of the evidence and conclusions drawn from the academic literature reviewed and analyzed for this study.

2 Regulatory framework

Energy efficiency has enjoyed unprecedented attention in EU energy policy in the past years. At the EU level, the efforts to codify the targets and policies towards increased energy efficiency came to fruition in 2012 in the form of a distinct energy efficiency directive. The member states have to implement the directive in the national legislation no later than June 2014.

2.1 Directive 2012/27/EC

The Energy Efficiency Directive (EED) 2012/27/EC, passed in October 2012, sets out the framework for the EU member states to achieve a 20% increase in energy efficiency. The directive defines methods for target setting, mandates alternative and complementary policies and actions for reaching the targets, and requires the member states to define long-term strategies. Furthermore and as a consequence of previous experience with the Energy Service Directive (ESD) 2006/32/EC, the EU defined specific, binding measures.

The key policies stipulated in the EED 2012 are:

- Mandatory energy audits for **industry**;
- Refurbishment of **public buildings** (at a rate of 3%per annum);
- Promotion of combined heat-and-power (CHP) and other means to increase **energy transformation** efficiency; and
- Enabling the **consumers** to better manage their energy consumption.

The scope of the EED sections that concern energy end-use extend from electricity and gas to any central source of heating supply, covering external district heating or central boilers for heating the entire building as well as providing hot water.

One important area of requirements aiming to facilitate consumer energy management governs the metering, submetering, and billing of energy consumption. For electricity and gas, the requirements in the EED 2012 build on, and further clarify, the requirements of the third energy package, namely the Directives on the Internal Market for Electricity and Gas (Directives 2009/72/EC and 2009/73/EC, respectively). These two directives require an 80% coverage of smart metering of electricity consumption by 2020 and an 80% coverage of gas consumption (without any specific deadline). For heat and hot water, and especially for the central supply of multi-apartment buildings, the directive requires accounting for and billing of individual consumption as well as providing billing information to the end user.

In short, the EED 2012 (Articles 9, 10, and 11) requires that:

- By June 5, 2014, EU member states must ensure that in all multi-apartment buildings supplied with heating or cooling or hot water from external sources, a meter is installed at the heat exchanger or the point of delivery to the building;
- By December 31, 2016, EU member states must ensure that in the multi-apartment buildings supplied with heating or cooling or hot water from external sources or from a central boiler, additional individual meters are to be installed in each apartment.
    - In case this is not technically feasible or cost-efficient, individual heat cost allocators at each radiator shall be used;
        - In case the use of such heat cost allocators is not cost-effective, other transparent methods of heat consumption measurement may be used.
    - These exceptions do not apply in the case of a major renovation or a new building. In these cases, individual meters are mandatory.
- As of December 31, 2014, all consumers, regardless of the metering type, are entitled to be provided with the metering data, including complementary information on historic consumption. The billing information should be provided at least once every three months (according to Annex VII, EED 2012).

Some indications of the interpretation of the "technical feasibility" have been communicated in an interpretative note of the European Commission (Guidance note on Directive 2012/27/EU on energy efficiency, SWD (2013) 448 final). As long as the metering does not require changing the existing piping in the multi-apartment building, it can be considered as technically feasible, which typically means that the hot water enters and leaves each of the apartments in one point.

For the cost-efficiency evaluation, the costs can be compared to the benefits for the end consumers, i.e. the users of the apartments. The benefits also include energy savings that are achieved through behavioral changes that are attributable to the metering data and more accurate billing information. It shall be noted that in this context the official explanatory note refers to an estimation of 30% energy savings after the introduction of individual metering.

2.2 Submetering and billing for multi-apartment buildings in Germany

The regulatory framework for the billing of heat energy and domestic hot water in Germany is defined in the ordinance on heating cost billing (*Verordnung über Heizkostenabrechnung,* *HeizkostenV*), last modified in October 2009 (Verordnung über Heizkostenabrechnung in der Fassung der Bekanntmachung vom 5. Oktober 2009, BGBl. I S. 3250).

The main principle of the ordinance is that the billing must be based on actual consumption. As of January 1, 2014, domestic hot water consumption also in central boiler set-ups must be measured, and thus shall no longer be estimated (HeizkostenV §9). This leaves only few exceptions to the rule, as listed in §11.

For an in-depth description and analysis of the technical and economic aspects of heat cost allocation in Germany, interested readers are encouraged to consult the report *Auswirkungen der verbrauchsabhängigen Abrechnung in Abhängigkeit von der energetischen Gebäudequalität* (Felsmann and Schmidt, 2013).

3 Towards the design of an optimal feedback system

In this section, the design parameters of an energy consumption feedback system are presented through international examples, and analyzed in the light of the state-of-the-art in the field. The majority of examples are selected from the energy domain, while the analysis draws on a wide range of literature in the relevant fields.

3.1 Theory of informational feedback

According to Ehrhardt-Martinez (2010), the main function of feedback is to make the consumption visible. Households use electricity and heating energy without recognizing the amounts of resources they are using. Consumers hardly notice when they waste or inefficiently use energy and are, therefore, unable to take appropriate measures to reducing their energy consumption. Feedback is a well-known medium to give consumer-specified information about their past behavior, with the aim of influencing future consumption. Raising awareness about the individual consumption should be the goal of every feedback mechanism.

3.2 Review of international experience in sub-metering

In several countries, pilot or even large-scale roll-outs of sub-metering have taken place. In this chapter, we give an overview of relevant studies and the saving potentials that could be triggered with the applied measures.

3.2.1 Sub-metering of heat and water

A research project jointly conducted by EWZ, ETH Zurich and a few other Swiss universities (Tiefenbeck et al., 2013) tested in a two-month field experiment with about 700 households a real-time display (consumption display) that measured the hot water consumption in the shower. The display recorded, showed and saved the water and energy consumption data of each shower taken. The trial was directed at finding out whether the display would indeed induce energy savings. The analysis showed that households with a real-time display on average saved 22% of their water and energy consumption when taking their showers. Furthermore, 8,500 liters of water per year and household were saved.

ista, a German energy service company operating worldwide, has gained international experience on energy savings through consumption-based billing of energy and water. It has tested several technical appliances for sub-metering, combined with consumption-based heating cost accounting. Their experience confirms that consumption-based billing is a prerequisite for all further energy efficiency activities. A relatively small initial investment resulted in energy savings from 15% to 30%, achieved by consumption-based billing (Barz, 2006 and ista Factsheet, 28.08.2013).

In addition, Hacke and Born (2011) have evaluated the effectiveness of ista's energy management system EDMpremium in private households. Users can view their monthly heat consumption via an online platform and thereby monitor their energy-related behavior. The authors found that those with access to the online platform saved on average 14% (after adjustments for weather conditions), while the control group without access to the information system increased their heat consumption by 2%.

In a field trial in Norway, enhanced billing was evaluated in 1989 (after a 3-year phase) and in 1995. The participating households received a graphical presentation of their current energy consumption in comparison to the previous year on paper. The test was a success, with an average energy saving of 10%. Additional energy conservation tips did not result in any additional energy savings in the trial. At first, the meter was read by the supply company, but in a later phase, the households were themselves responsible for the meter-readouts. After the very positive results, the enhanced billing was made obligatory in Norway in 1999 (Wilhite et al., 1999).

In Serbia**,** a project on consumption-based billing in the residential sector was conducted. In the project, consumption-based billing was compared to the traditional tenant-level billing. The consumption of heat and electricity was monitored and recorded during two heating seasons (2006/07 and 2007/08) and in three identical apartment buildings, each with twelve floors, 76 apartments and 4,500 m^2 of total heating area. Two of the buildings were not supplied with consumption-based bills, but instead with the tenant's bill of the building. The consumer-specified billing resulted in a heating demand that was 20.6% lower compared to a situation with traditional tenant billing (Stojiljkovic and Jovović, 2010). Additional information was not provided in this study.

In Wellington, USA**,** Vogel et al. (2012) conducted a study with 8 million data records taken from Wellspring sub-metering devices across ten different properties with multi-family dwellings that were equipped with a wireless sub-meter. It was tested whether the sub-metering rollout would lead to reduced water consumption. The study compared the consumption of metered buildings with several un-metered buildings. The results show an average saving of 27% of water in sub-metered dwellings compared to the unmetered buildings. The water conservation was mainly driven by a decrease in the frequency of toilet flushing (e.g. by not using the toilet as a garbage disposal), shifting from baths to showers, and reducing the amount of water used per shower

The National Multiple Family Sub-metering and Allocation Billing Program showed similar results: the houses using sub-metering for the water billing used significantly less water (around 15.3% less) than the traditionally billed properties. The program was carried out in 2001 and 2002 together with the municipal utilities of 13 cities (Mayer et al., 2004).

The sub-metering of heating and warm water as well as the consumption-based billing is yet a quite recent field of research. However, some studies on water and heating sub-metering have been conducted and they all show highly positive results concerning potentials for energy and water savings.

The baseline consumption level seems to be one important factor explaining the achievable energy savings through tailored feedback or individual billing.

3.3 The comparability of feedback systems

Feedback can be provided in many forms and using many different media. A main distinction can be made between paper-based feedback, such as a supplement to the bill, and electronic feedback, which can again use multiple channels, such as the Internet, in-home displays, or smartphone apps. Each system has its very own attributes, which makes fair comparisons difficult. While it is uncertain in which ways the medium impacts possible behavioral changes, some authors do not find any difference (cf. CER, 2011).

Along these lines, Fischer (2008) compared the two types of feedback media (paper-based and electronic). While paper does not inflict any technical barriers and is inexpensive, it does not allow any interaction and can, therefore, only convey static information. For electronic displays, there exists a wide range of possible implementations, such as in-home meters, meters specific to an appliance, Internet portals, smartphone apps, and ambient displays. While the earlier can all be configured as desired, the latter operates at a much lower level of cognition. Without the need of processing, the user immediately perceives the information in an abstract way (e.g. by using a single color signal). Obviously, the type and extent of information that can be transmitted in this way, is rather limited. Also, similar to paper-based feedback, no interaction is possible.

Froehlich (2009) brought up the question of whether information on an in-home display should always be available or only under specific circumstances, such as excessive energy use. While punctual feedback can increase a user's attentiveness, it might be counterproductive to triggering a continuous process of increasing awareness of one's own consumption. Unless it is adaptively designed, it also brings up the issue of motivating low consumers to consume more as long as the device does not "intervene".

Roberts and Baker (2003) found no evidence that advanced meters are necessary to improve feedback (though they could of course help if this aspect is a feature of their introduction). Well-designed consumption feedback provided with the bill can be just as effective, less costly, and easier to introduce.

As detailed in Section 3.6, the medium for transmitting feedback is not as decisive as tailoring its presentation to the user in question. The critical factor hereby is the attention and the involvement of the user, which can be gained by the use of color coding and illustrations. The decision about the appropriate medium should be based on the contents of the feedback to be provided (some of which might be easier to provide with one or the other medium) and total costs of the system in question, which also depends on the frequency of feedback updates.

3.4 Ways of communicating the feedback

In contrast to the present billing and information system in use, in Germany a wide range of several other feedback and information systems is possible when using international experience with some of the relevant technologies. An adequate dimension along which the different communication channels can be arranged is the technical complexity of their implementation. An overview of this is given in Figure 1.

The range starts with low technical paper-based billing, continues with feedback delivered via a website, goes on to smartphone-based feedback, and ends with an in-home display that can even be appliance-specific. The chosen dimension in order to structure the ways of communication is not selected randomly. The higher the complexity of a feedback system is the more consumers are excluded because of low technical interest of the average user or the lack of spare time. Especially when it comes to the in-home display, the risk of not understanding the diverse functions and management options could actually lead to an adverse and undesired effect of not saving energy but rather increasing it. The advantages of such technically more complex feedback systems, such as a higher possible frequency of feedback and more detailed feedback information (that theoretically lead to higher savings), cannot always compensate the lack of the average user's ability to manage such a system. Whereas the average energy consumer is more used to the digital version of a website, a smartphone app might already be too complex for a large share of the population.

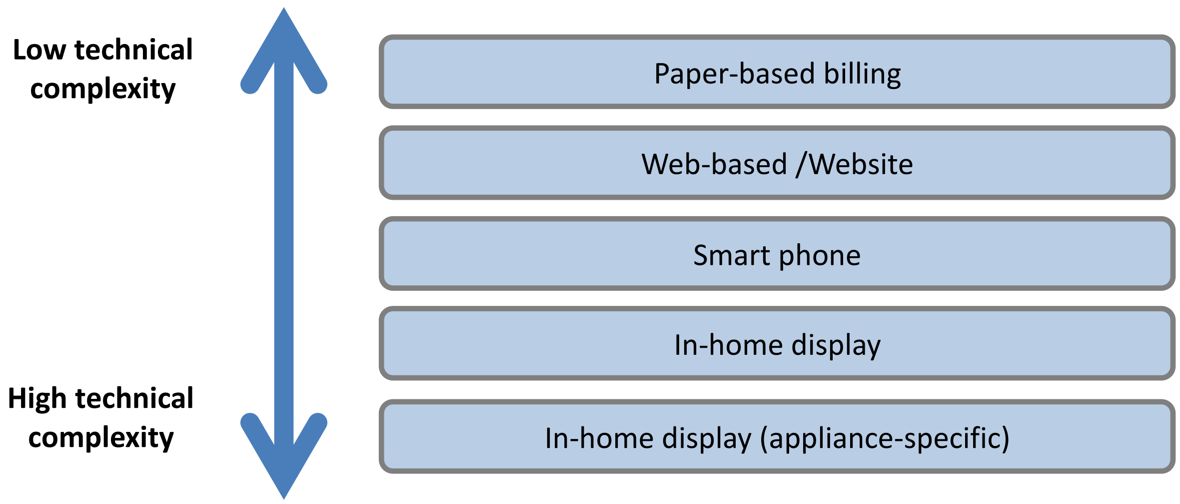

Figure 1: Level of complexity by energy-saving measure

Another main difference within the types of communication is their featuring of interaction. Technically more complex systems, such as an in-home display, give the consumer the possibility of choice, e.g. on how the data should be presented. Hence, it involves the customers in that it raises and tries to maintain their attention, and in that it allows some space for tailored solutions. As has been mentioned before, this way of communication will only show an impact if the consumer is sufficiently skilled or motivated to interact with this new technology (software). A paper-based solution might provide more information at a glance, but gives no opportunity of drilling down to specific data, which might be an important piece of information for a consumer on the way to identifying energy saving potential.

In the literature, numerous different feedback measures were tested in order to gain new insights into which way of communication leads to which kind of behavioral change and, accordingly, what kind of communication channel is preferable.

Karjalainen (2011) distinguished between three main types of feedback: direct feedback, indirect feedback and inadvertent feedback. Additional dimensions along which feedback can be adjusted are illustrated in Figure 2 and discussed in the following.

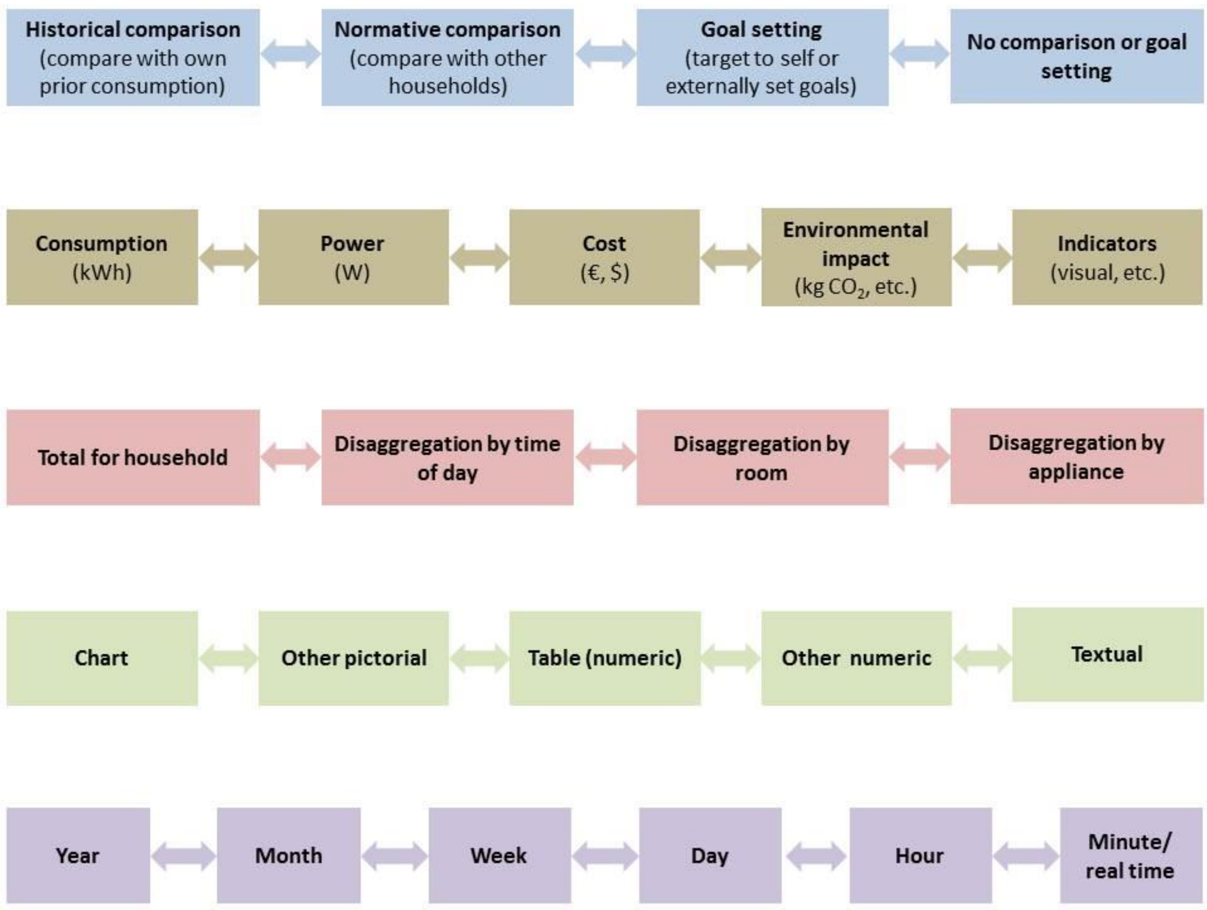

Figure 2: Feedback types according to Karjalainen (2011)

Karjalainen further described the types of possible comparisons, the types of goals that can be followed, the framing of the presentation, possible details of the disaggregation, the visual types of presentation, and the reference time scale which can be used (see Figure 2). He advised to design the interface in a simple way, such that it is not overloaded with information that might not even be immediately usable. This also means that the display needs to be consistent within itself (e.g. concerning labels and interactions) as well as with the user's earlier experience and expectations. Generally, graphical displays are to be preferred to text when space- or time-related information needs to be conveyed. Tables, on the other hand, can be useful for detailed comparisons of ordered sets. In a user study, the author found that costs are highly valued by consumers, as well as detailed information on how much each appliance consumes. Finally, they liked a historical comparison with their own consumption to be better able to evaluate the effectiveness of their behavior and to adjust it accordingly.

Fischer (2008) reviewed 22 feedback studies and drew the following conclusions concerning ways of communication: Among the most effective feedback systems were those with computerized feedback that offered the consumer multiple options (e.g., consumption over various time periods, comparisons, additional information like environmental impact or energy-saving advice). Interactive elements, such as self-meter reading or managing the system, made them very successful.

Farhar and Fitzpatrick (1989) reviewed a collection of past studies and compared, among others, the effects of a feedback by display with the feedback that is printed on paper (utility bill, yearly one-time reports, cards, etc.). They concluded that the examined studies offer no evidence of displays being the more effective feedback mechanism.

Between 2009 and 2010, a pilot study by CER for Ireland (CER, 2011) took place in order to test the application of smart meters in a broader range. Alongside with the electricity monitor of the smart meter, a bi-monthly bill and a monthly bill with both an energy usage statement and a web access providing their energy usage information were tested. The most effective feedback measures were bi-monthly bills in combination with energy statements and real-time displays, yielding together an average energy saving rate of 3.5%. No significant differences were found within the medium of feedback, i.e. whether it was a display or a paper bill.

Schleich et al. (2013) tested two types of feedback measures in a field trial in Austria: Feedback via a web portal and written postal feedback. Participation in the pilot group was random, but households were able to choose between the two types of feedback. The result here was that there is no difference in the savings of both feedback types. Both groups achieved the same savings of around 4.5% of their consumption. The fact that the consumers were able to choose between the feedback types can explain the equal effect of different feedback methods.

Sipe and Castor (2009) tested about 350 real-time feedback devices from January until August 2008 in Oregon, USA. While the treatment group achieved some energy savings, the same could be monitored for the control group. They conclude that instantaneous feedback does not necessarily lead to larger savings.

Haakana et al. (1997) studied the effects of providing feedback as written material versus video messages in the field of district heating in Finland. While their participants already saved on average 5% just upon being obliged to report their own meter readings every month, additional feedback including comparisons to other households and advice for energy-saving potential led to savings of on average 7% for the written material and 9% for the video messages.

The mentioned studies provide some evidence that the variation of the medium might not have a big impact on consumer behavior. In this context, the financial aspects of introducing a certain measure might also be taken into consideration. In general, the lower the technical complexity of a feedback system, the lower the investment costs can be expected. However, different media achieve different frequencies. The effect of frequency on behavioral changes is noteworthy and will be discussed in the next section.

3.5 The question of feedback frequency

The differential effects of the feedback frequency on energy consumption have so far only been investigated directly by a few pilot studies, and often the type or design of feedback is varied along with the frequency. For example, continuous digital feedback is compared to less frequent feedback on paper, or only the effects of the random assignment of one specific feedback mechanism or device are studied. In this section, we first look at two exceptional studies (both regarding the setting of the social comparison), and subsequently deal with several review or meta-studies that attempted to draw some conclusions on this question by combining the findings of a number of such pilot studies. Finally, we mention two studies touching on consumer preferences for frequency.

Allcott (2011) found savings resulting from letters sent to USA consumers comparing their electricity use that were 0.5% higher to those of their neighbors when such letters were sent monthly rather than quarterly, and randomized between-subjects (p.1087). However, Ayres et al. (2013), focusing on peer comparisons, reported on a related study with randomization between monthly and quarterly reports regarding both electricity and natural gas consumption, and concluded that quarterly effects are statistically indistinguishable from monthly effects (p.18). Because of the lower costs, quarterly reports would thus be preferable.

Abrahamse et al. (2005) reviewed several pilot studies on the effects of feedback in different frequency categories (pp.278-279): continuous, daily, and weekly or monthly feedback. However, they find that there is no general trend in the results: in any category; very positive results with up to 12% persistent energy savings can be found as well as studies without any significant effect, or with even negative effects for *ex-ante* low energy consumers, or at some time after the treatment.

Darby (2001) is more conclusive on the effect of frequency, where she divided 34 studies into the categories “direct feedback” and “indirect feedback”. Direct feedback studies showed savings of 5% to 20%, whereas indirect feedback studies only showed savings of between 0% and 15% (see Table 1 in Darby, 2001, for more details). Direct feedback hereby refers to feedback that is available on demand (for example, by looking at the meter or using an online platform), whereas indirect feedback is processed data made available by the utility (for example, bills). Similarly, Fischer (2008) categorized projects into such that provided feedback less than monthly, monthly to weekly, and daily or more. It turned out that none of the “less than monthly”, and all but one of the “daily or more” projects are among the best-performing (as far as they can be compared). In the “weekly to monthly” group, there were some well-performing but also a number of quite low-performing projects. This indicates that immediate feedback could be very helpful while weekly to monthly feedback may be helpful, but is insufficient for best performance on its own.

Vine et al. (2013) also conclude that more immediate and frequent feedback is more likely to result in positive behavior change, mainly based on the many success stories of continuous feedback studies (p.11). Likewise, Froehlich (2009) observed that when no savings could be promoted, the feedback frequency was insufficient (such as billing only twice a year) or there was no saving potential left in the households in question. Computerized feedback (in-home smart meter, flat-screen monitor in the kitchen) has been proven to be most effective, mainly because it offers various feedback options such that users can adjust it to their specific needs and interact in the way they like.

Ehrhardt-Martinez et al. (2010) even concluded from their meta-review that there exists a positive monotonous relation between frequency of feedback and electricity savings. They find that savings of up to 12% percent can be achieved when feedback is given at the time of consumption and specifically for the appliance in use.

The original report from EPRI (2009) is itself much more careful in drawing such a conclusion (based on 57 primary studies) and rather stresses the broad range of factors and their interactions that affect the effectiveness of feedback (see Table 3-1 in EPRI, 2009, for more details on the effects found in the frequency categories).

Concerning preferences of billing information, Sernhed et al. (2003) found that most survey participants are satisfied with the frequency they get their electricity bills (each month, every other month, or quarterly). Likewise, Fitzpatrick and Smith (2009) performed a survey on consumer feedback preferences, finding that 49% of the participants wanted real-time feedback, 33% when they received their bills, and 28% when something changed. At post-interviews, however, all participants could see some value in simple real-time feedback to raise awareness.

3.5.1 Interpretation of frequency and granularity

It is quite useful to distinguish between feedback frequency and feed-back granularity: the first refers to the frequency the feedback is actually provided, while the second refers to the time intervals of the measured and communicated consumption data. The decisive factors for the frequency assessment stem from the consumer behavior and preferences, whereas the data granularity is also dependent on the available metering and data processing technology.

In general, the studies show a positive correlation between feedback frequency and energy savings. The frequency alternatives span from annual billing to real-time power monitoring. The majority of the studies or pilot programs concern electricity consumption. Real-time monitoring of heat or hot water consumption can be claimed implausible with great certainty, but the exact threshold level of plausible feed-back frequency in the case of heat and hot water is difficult to determine.

The transferability of the findings across energy carriers can be evaluated along two dimensions:

First of all, the time constants in the market and in the consumption dynamics differ from energy carrier to carrier and from consumption area to consumption area. Secondly, the utility from consuming energy is either direct or indirect.

The value of electricity, both in the market as well as for a single consumer, is sensitive to time variation. The cost basis for the retail tariffs is the time-dependent value of electricity in 15-minute-intervals, as the imbalances are measured and charged from the electricity retailers in the said 15-minute granularity in the form of imbalance pricing (in German: Ausgleichsenergiepreis). As for the individual consumer, certain components of the electricity consumption are almost totally temporally inelastic. Combining the two aspects, namely variability of the cost of electricity, and variability of the value of electricity, one can conclude that the time granularity of 15 minutes (or less) is relevant in the case of electricity. This holds, however, only for the temporally inelastic part of demand.

The natural gas market exhibits similar characteristics as the electricity market, i.e. trading in high frequency time intervals. Also, household consumption of gas is to a certain degree highly inelastic, especially for cooking and direct heating of hot water. Demand for district heat is less sensitive to small time constants: Regardless the source of heat, the thermodynamic characteristics of a building substance create certain stickiness in the demand. With these observations one can claim that the shortest meaningful time constant is the smallest for electricity, followed by natural gas, and district heat, respectively.

The second dimension for the interpretation of the results across energy carriers, namely the question of direct or indirect utility, can be used to divide energy consumption into two baskets: consumption that is used to generate an energy service, e.g. lighting or dishwashing (= indirect utility) into one basket, and consumption that creates wellbeing as such, e.g. heat or hot water (= direct utility) into the other basket.

Along these intuitive simplifications of different uses of energy and the related time constants, some broad interpretations can be drawn. As long as the frequency considerations are in the range of weeks, months or quarters, the energy carrier should not make a difference. This is to say that energy saving results drawn from studies of one energy carrier can be, ceteris paribus, transferred also to other energy carriers. It could even be argued that low-frequency feedback of heat consumption is more informative than low-frequency feedback of electricity consumption, as the feedback intuitively relates to the comfort (= utility) derived from heat, while electricity feedback must first be converted to energy services for linking it intuitively to derived utility.

As for the studies of high-frequency (and small granularity) feedback, the interpretation of the results is a bit more difficult. Undoubtedly, the inherent time constants of each of the energy carriers are somewhat different. The dimension of direct vs. indirect utility, and the question of demand elasticity may, however, bring the energy carriers closer to each other than appears at first sight. Due to the thermodynamic aspects mentioned above, the shortest meaningful time unit for domestic heating will never get shorter than, say, a couple of hours. Consumption of hot water, on the contrary, does not possess any such characteristics that would speak against interpreting results of high-frequency electricity feedback also to the context of hot water.

Bearing in mind the inherent characteristics of the different areas of energy consumption as well as the thermodynamic constraints where applicable, the findings of the role of feedback frequency are with caution transferable to other energy carriers.

3.6 Designing the optimal information for feedback

3.6.1 How to design an interface

Alongside with user-specific influences as the independent variable, the representation of information can also have a significant influence on the behavior of the interacting user. In the context of user interfaces of computer-aided support systems, there already exist a number of studies that establish such interdependence, some of which are summarized next.

Saleem et al. (2007) developed an improved design of an existing system for medical records. The goal was to organize and report all necessary information in a way that it could be most easily used by staff members. They used a simulation study as well as a card-sorting task. The latter helped to better understand the mental model of the user in order to adjust the system organization to the internal organization. Test subjects (doctors) were asked to group all data in a way that suited their needs. The system that was built according to the research results showed much better performance in the tests than the existing system.

Beginning in the 1990s, Vicente and Rasmussen (1992) ventured to develop the so-called “Ecological Interface Design“, which offers an open access to interface design. It is supposed to enable a system to offer the correct information and interaction possibilities, even in unforeseen situations. This means that it needs to support a user dealing with complexity. It rests upon the three levels of cognitive control: skill-based control, rule-based control, and knowledge-based control (cf. Rasmussen, 1983). A successful interface needs to address each of these levels in such a way that there is a direct link between the presented information and possibilities for action. Furthermore, for each level, there needs to be a correct representation of the system's boundaries as well as an externalized mental model of the system.

Duncan and Holliday (2008) stressed the importance of the information architecture when developing a website and describe a very extensive process for restructuring a library website. Such a website is directed at students and other users in helping to find certain information (e.g. book availability and library services). In each phase, they employ several methods, including surveys, card sorting, and classic usability tests, where certain tasks need to be fulfilled within a given period of time (i.e. under time pressure). Their approach is marked by many iterations during which all stakeholders are included and repeatedly asked for suggestions.

3.6.2 Participatory and user-centered design

There are several approaches to design and development processes. For making the right choice, the type of product as well as the type of user is decisive. Especially the latter has recently gained considerable attention and cumulates in the literature on user-centered design. This is supported by several design approaches that involve the user early and in an iterative design process. Brandt (2006) suggested the use of games and scenarios to develop a common sense of the situation and to enable the participants to actively discuss their needs and desires.

Sanders (2002) distinguished between user-centered and participatory design as well as the enhancement to experience design. According to her, in a user-centered design, the focus is on the object that is to be designed in such a way that it fulfills the requirements of the user. In participatory design, the roles of the parties proactively involved in the design process become blurred. Experience design introduces yet another new dimension, namely the feelings and emotions of the user. As these are determined by previous experience of the individual, successful communication first requires knowledge about these cognitive processes. The challenge is to elicit these and implement them in the product.

Ellis and Kurniawan (2000) used the approach of participatory design for creating a website with and for elderly users. With the help of a questionnaire, they first established a user model to better understand the user group they were facing and to be able to identify important design parameters. Subsequently, elderly users could try out prototypes of the website in twelve consecutive sessions while discussing with the programmers. The authors concluded that for a successful project, the most important factors are building up trust, explaining the relevance of the project for the users themselves, and interacting in a mutually respectful way.

Fischer (2003) defined meta-design as distinct from user-centered and participatory design. Its goal is not to develop closed, key-turn systems, but rather to give users a tool and the opportunity to actively contribute to the system. This means that the designer only creates a framework within which the system can grow and emerge. The idea behind this is that users in search of a solution to fulfill a task are the only ones who really know and understand the problem in depth.

Constantine and Lockwood (1999) and Constantine (2002) introduced the notion of usage-centered design. The difference to user-centered design is that no user model is required, as the focus is on the task to be fulfilled. This means that a system mainly needs to support this task and that the user interface needs to be adjusted to the relation between the user and the system.

3.6.3 Content of feedback information

An important notion is that feedback does not add any information beyond what consumers can already find on their energy meters – it only delivers it in a different way and often with a different framing. This change in communication can already lead to energy savings of about 10–20%, according to Stern (2000). He also established that video messages are typically much better processed than written messages, resulting in better ways of implementing the advice and, subsequently, in achieving higher energy savings. Feedback also provides highly credible information, compared with supposedly expert advice. One of the most important issues, however, is that it needs to be simple to be successful.

In combination with other motivating factors, feedback can substantially increase energy savings. The constant reminder of an appliance-specific display can be the key to long-term energy reduction, because it links the information to the cause. Wood and Newborough (2003) proposed that a task-specific display placed in proximity to the appliances would give the user a comprehensive way of viewing her energy usage around the house – e.g. a "cooking" display which collects information from the oven, hob, microwave, kettle, etc. This approach integrates feedback options into the everyday routines. Wood and Newborough also pointed out that goal-setting (e.g. in kWh of energy consumed) can further enhance the users' ambitions for reducing her energy consumption.

Jacucci et al. (2009) concluded that mere information about kWh consumed is no sufficient feedback, and suggest that it should be related to the energy conservation goal. In order to help fostering energy-saving behavior, feedback should be given both on the level of appliance to improve the understanding about where energy can be saved, but also on the overall household level to prevent a rebound effect. Such rebound could arise when feedback is only given on the more detailed level, for instance, if only some appliances are closely observed or if users want to reward themselves for saving a lot of energy with one specific appliance. Furthermore, the user should also be able to observe the development over time to observe the effectiveness of his behavior.

In contrast to Karjalainen (2011), Froehlich (2009) established that monetary feedback should be avoided, due to its close relation to income and the general economic situation. Being an indirect measure, it also does not sustain motivation in the long run.

Furthermore, it was found that the energy usage statement was only useful in supporting consumers that were already engaged in energy reduction. It did not of itself promote the required process in behavioral change (CER, 2011).

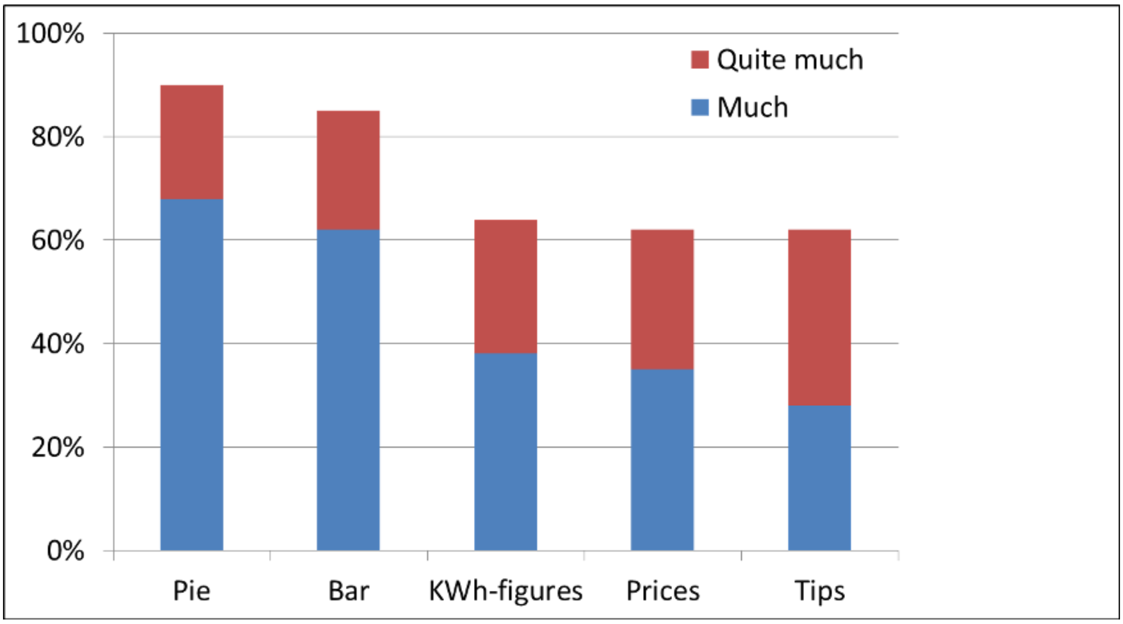

Figure 3. Acceptance of different types of illustration according to Arvola et al. (1999)

3.6.4 Visualization of information

Beyond the question of whether to provide the feedback electronically or on paper, the question of how to best visualize it arises as well. From an ergonomic perspective, some studies exist on the perception and subsequent processing of information. Color and objectiveness have been shown to play a role in information integration as well as for focused attention (Wickens and Andre, 1990). While the distance between individual displays does not seem to have an effect, color and form exhibit opposite effects, i.e. a monochrome objective display supports information integration, whereas a colored bar diagram improves focused attention. When designing an interface, one thus needs to investigate which type of information processing is to be supported before choosing the design elements.

Van Duyne et al. (2003) illustrated the significance of known patterns in website development. They hereby denoted a common language that is understood by all users. This can exemplify in well-known buttons that are designed in a way that they are immediately recognized and help to navigate and use a website.

One example of a well-known pattern is the feedback provided by a traffic light. A green light means that everything is alright, or, if transferred to energy consumption, that the household is doing well in terms of its energy savings. Similarly, a yellow or a red light means that consumption is in the middle range or out of limits, respectively. However, such visualization might be exciting in the beginning, but if it is not perceived as useful in everyday life, users are bound to lose interest over time (e.g. Strengers, 2011).

Pierce et al. (2008) differentiated between pragmatic and artistic visualizations. Thereby, the earlier usually refers to quantitative information that is visualized in the form of bar graphs, charts, and the like. Although the information is very precise, users often need time to understand its meaning. Artistic visualizations are more intuitive, but at the same time usually less precise. An example of this would be the representation of fuel consumption as blooming flowers as it is done in the Honda Civic hybrid car.

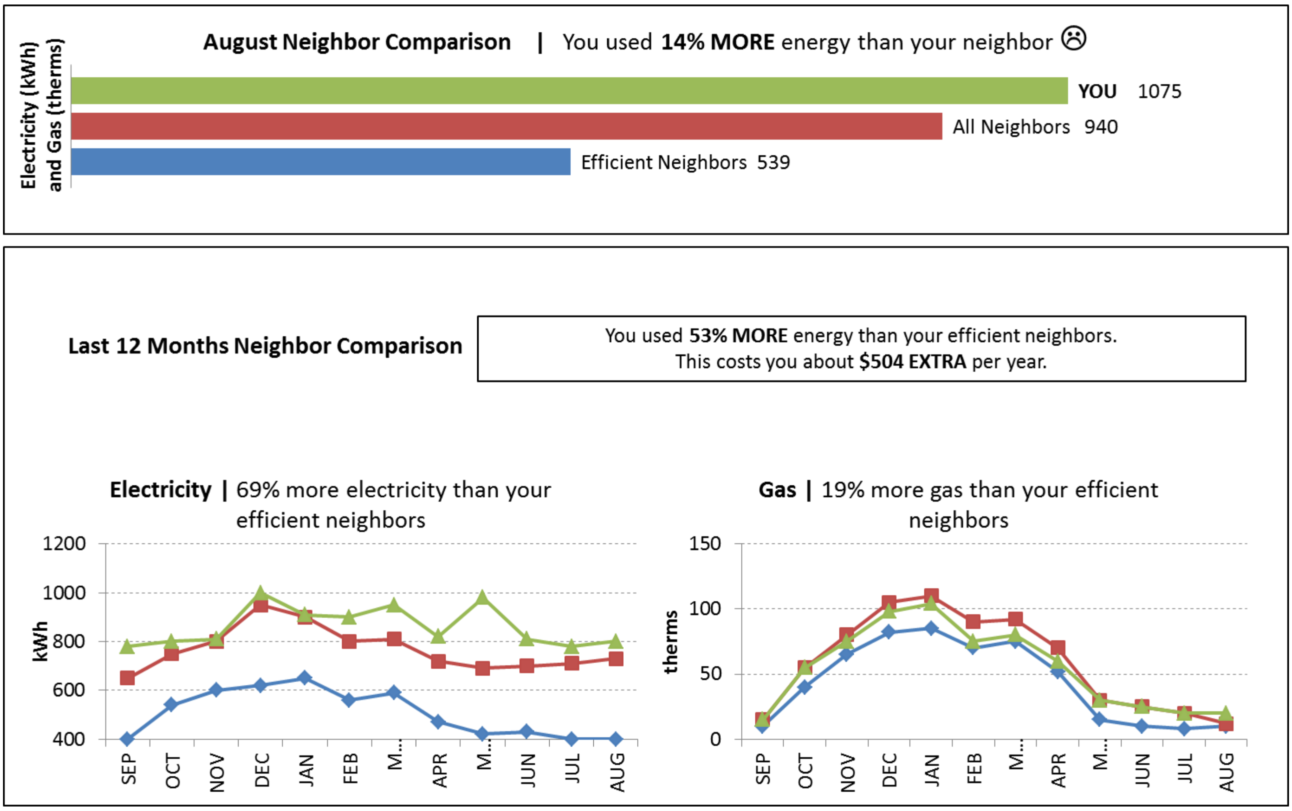

Figure 4. Example for including illustrations in bills or internet portals

3.7 Additional information and measures

In order to be most effective, not only the contents and the visualization of feedback play a role, but also seemingly side issues, such as accompanying information or framing.

Harmsen - van Hout et al. (2013) quantified the value of 'green framing' through a choice experiment where subjects chose technical, home-related energy saving measures (ESMs) after valuing the attributes of a set of alternatives. Green framing was tested through a treatment where the one half of the subject pool was exposed to a scenario description where the energy-savings attribute was formulated as an environmental benefit and the other half a scenario description focusing solely on the economic benefit of the energy-savings attribute. It appeared that financial and environmental descriptions of the energy-savings attribute indeed led to significantly different attribute valuations.

Roberts and Baker (2003) assessed that consumer feedback is most effective when it is immediate, prominent, accessible and specific to the consumer. Under these circumstances, consumers seem to respond appropriately to historical comparison information on their bills and in- home meter displays. In their study, consumers report being motivated to act to reducing their energy usage by graphs and bar-charts on bills and comparing their consumption with other groups of households. As described in the section on participatory design, the authors also suggest that engaging consumers in the design of feedback information leads to more effective designs and increases the likelihood of creating presentations which meet the full range of consumer preferences of options to receive and assimilate information and data.

Several studies have shown that the comparison with one’s own consumption (as can be done with time series data) is much more appreciated than comparisons with others (e.g., Midden et al., 1983; Schultz et al., 2007; Kantola et al., 1984) Nevertheless, in order to keep consumers motivated, it should also be responsive to small savings for illustrating possible trends early on (Liikkanen, 2009).

While historical information might provide some such motivation, this will only be the case if household consumption is increasing. More effective and motivating feedback is likely to be provided by normative comparison with similar households or, more straightforwardly, with a target reduction in consumption based on national targets (Roberts and Baker, 2003).

Another measure for motivating consumers to save energy is social sharing (Froehlich, 2009). By publishing usage data on social platforms or social networking sites, pressure can emerge that spurs the involved households to reach some implicitly or explicitly formulated goal.

Usage information can further be enhanced with recommendations on how the behavior can be changed to save more energy. This advice should be specific and as close (temporarily and spatially) as possible to the field of action. Assuming there are several task-related displays as proposed by Wood and Newborough (2003), the one for cooking should then not suggest to take shorter showers, but to put a lid on a pot or to make sure that all pans have flat bottoms.

While Figure 3 depicts which kind of visualization is most appreciated by consumers, Figure 4 gives a hands-on example of providing feedback with additional information. It includes the development of one's own consumption over the entire year as well as some comparison to the neighborhood. The usage of colors and icons represents known patterns as discussed above. The smiley gives feedback at first glance without the need of costly cognitive processing, while the information about costs can be a motivating factor.

4 Focusing on the energy consumer

Studying the effect of feedback mechanism does not only include the examination the technical aspects like choosing the medium, designing the display, varying the informational facts or changing the frequency of feedback but furthermore to have a closer look at the *'place'* where the information should achieve a certain effect, at the consumer. Studying the consumers and their specific characteristics lead to a higher understanding of which feedback mechanism works the best and which one might cause problems of acceptance.

4.1 The theory of consumer preferences and behavior

For decades various disciplines, like the social and (behavioral) economic science or environmental psychology researched 'energy consumer' to better understand and explain his behavior. Yet still, some authors claim that there is a lack of systematic studies, because there is no easy answer as to how to elicit a change in behavior. There are no clear guidelines that relate to specific behavioral instances. Uitdenbogerd et al. (2007) suggested that this is due to a focus on instruments that can be implemented in practice without regard to the changes they need to induce. However, the effectiveness of single components can be increased when being implemented in combination with others.

An important study from the sociological and sociotechnical discipline is the one of Wilson and Dowlatabadi (2007). They noticed the gap between knowledge and change in behavior and further explain this process of decision-making along these stages.

Rogers (2003) focused on the question in dependence of which conditions the consumer purchase a new technical EE-appliance. He found that the rate of adoption is depended on five attributes concerning the consumer: His relative advantage, the compatibility, the complexity, the trialability and the observability. A number of further studies documented this relevance of the mentioned attributes (a.o. Darley and Beniger).

Based on an experimental study, Sütterlin and Siegerist (2011) formed six consumer groups along the question "Who puts the most energy into energy conservation?" They found that the largest group (26.4%) consisted of participants who were aware of their energy consumption but had no high interest in changing their behavior. Nevertheless they demonstrate considerable energy-conscious efforts. Nearly another quarter of the participants (25.1%) were characterized by achieving only less energy-savings and only for financial considerations. The highest savings were achieved by only a small percentage of 15.6% for idealistic reasons. The other groups were marked (i) by only engaging in energy-saving efforts as long as they involve no financial disadvantages, (ii) by considering their ability to perform energy-saving behaviors as rather limited or (iii) by not feeling responsible and not being motivated by financial incentives. As a conclusion, most participants were willing to reduce their energy consumption but with different motives. These groups especially show existing contradictions like awareness combined with no interest in behavioral changes. This knowledge is important for developing and implementing measures that can fulfill the specific needs, desires, and interests of the different types of energy consumers

Darby (2006) focused on the question whether savings are persistent. She noticed that the savings will only be permanent if either the feedback supports 'intrinsic' behavior controls, in other words, if the consumer develops new routines and habits concerning their energy behavior or if the feedback leads to the purchase/investment in, for example, an EE appliance or insulation. It is important to make a consumer understand what the relation is between his own behavior and the resulting energy consumption, which cannot be assumed to be obvious. Therefore, a pure feedback might not be sufficient, but further advice can be helpful in achieving long-term savings.
The theory and its findings should help us now to better understand the following passages about:

- why the feedback measures lead to diverse kinds of changing behavior (Section 4.2),
- why some savings are persistent while others diminish (Section 4.3),
- to what extent the savings account for the heterogeneity of consumer (Section 4.4)
- and why there will always be some barriers in acceptance (Section 4.5).

4.2 Variation in change of behavior

When looking at the energy behavior of consumers one can find a broad range of possible reactions. To give an overview of all possible behavioral changes a categorization is helpful. One main distinction can be identified in the frequency of action: a behavioral change as a result of feedback or additional information can be expressed in one single action, such as reprogramming the thermostat, or in frequent habitual changes that affect daily routines, such as only venting the room if the heating is switched off. This dimension must be taken into consideration when trying to achieve habitual changes in the heating behavior of consumers.

A second influential dimension is the intensity of monetary costs. In order to lower the (warm water) heating cost, consumers often purchase new applications, such as an energy-efficient shower head. These actions are taken once, which means that no immense long-lasting effort is necessary. On the other hand, these investment costs are often an influential barrier if the technologies are not affordable for the average household or if the perception of the amount of investment exceeds the long-term savings that are in turn not always very easy to calculate. When trying to achieve a change in behavior, it is helpful to keep these two dimensions in the back of one's mind. The following table based on ideas of Ehrhardt-Martinez (2011) gives an overview.

Table 1: Types of behavioral change

	Infrequent	**Frequent**
Low-cost/ No-cost	Energy stocktaking behavior and lifestyle choice	Routine and habitual behavior
	• Reprogram the thermostat • Lower temperature on hot water heater • Program a specified user heating profile	• Air room only if heating is switched off • Switch off heating when leaving the house • Short and intense ventilation, instead of continuously tilted windows
Higher cost / Investment	Consumer behavior and technology choice	
	• Purchase new insulation • Purchase energy-efficient shower head • Purchase water saving toilet flush	

In any case, this information reveals that there are different consumer types with either a tendency to change their behavior or otherwise purchase an energy-efficient application. If giving enhanced feedback about individualized energy behavior, the energy-conserving tips should include both dimensions.

In the literature, there are international studies focusing on different types of behavioral change if energy feedback measures are applied.

The Oslo-Helsinki experiment (1989 – 1992) tested an enhanced two-monthly energy billing as a feedback measure. The bill incorporated a graphical representation of this versus last year's electricity use (weather-corrected) and energy-conserving tips. Change in behavior was mainly found in better management of the heating system (seasonal and daily), the purchase of more energy-conserving devices, such as a more recent freezer type or energy-efficient light bulbs, and the purchase/usage of a portable electric heater. Some other changes were found in lightning, washing, and ventilation routines. The change of behavior resulted in an average of 10% of saved electricity in comparison to the control group. The most interesting part of this study is the participants' reactions at the end of the experiment. When asked in the beginning of the interview whether they had done anything differently, very few responded that they had taken any specific action for saving electricity. Only during the interview they remembered how they changed their routines. This reveals how a feedback measure with energy-conserving tips can unconsciously lead to long-term, new energy and heating habits.

A study of Abrahamse et al. (2007), which took place in the Netherlands, used a website as a feedback method. At the beginning, the consumers were asked to fill out a questionnaire about their energy behavior regarding some of their appliances and received information about energy problems. An energy analysis program could then give individually tailored energy-saving tips in response to the questionnaire. Furthermore, they were given a 5% energy-saving goal. After some time, the consumers were again asked to fill out a questionnaire concerning their energy behavior, so the program could recognize and calculate the achieved energy savings for giving updated and customized feedback. The changes in behavior were significant and mainly consisted of either lowering the daytime thermostat setting or in using warm water less often.

In the Massachusetts PowerCost Monitor Pilot Program, Siems (2009) tested real-time feedback by installing in-home displays and found that consumers tend to switch off appliances (TV, lights, computer, charger) when they are not in the room in order to save energy. They furthermore lowered the temperature setting and used aeration less often. 60% of the consumers in the program retained these actions even twelve months after installing the display.

Ehrhardt-Martinez (2012) tested three different types of feedback and noticed different behavioral responses for different measures. She tested enhanced billing, monthly online feedback and real-time feedback. Each feedback led to different responses. The actions taken most often for each feedback method can be seen in the following table.

These findings reveal the extent of variation in consumer reactions to different feedback methods. As can be seen, the more frequent (and therefore more detailed) the feedback, the more specific and application-oriented the reaction. This makes it easier for consumers and service providers to identify specific energy-saving measures with a higher savings rate without reducing the level of comfort. When decreasing the frequency of the feedback, the consumer is less able to find her individual energy-saving potential, which dissolves within the monthly summarization of heating and energy usage. Especially for low-frequency feedback measures, additional specified energy-conserving tips are necessary for giving the consumer the opportunity to decrease her energy consumption. The more frequent the feedback, such as provided by real-time displays, the less additional information or advice is necessary.

Table 2: Behavioral changes in response to different feedback measures

Feedback Measure	Tendency of reaction	Chosen actions
Enhanced billing	• Slightly more likely to make investments in energy-saving technologies • More likely to turn off or unplug appliances, devices and electronics • More likely using alternative technologies such as CFLs	1. Turn off lights (26.4%) 2. Replace incandescents with CFLs (23.6%) 3. Change thermostat setting (10.6%)
Online feedback	• More likely to engage in conservation behaviors	1. Replace incandescent bulbs with CFLs (70%) 2. Use blinds during summer days (66%) 3. Wash larger loads of dishes (66%)
Real-time, **In-home feedback**	• More likely to use conservation settings on appliances and electronics (device control, performing maintenance)	1. Use power strips on home entertainment system (38%) 2. Use power strips on home computer system (36%) 3. Reduce wattage in multiple bulb fixtures (32%)

4.3 Level and persistence of achievable energy savings

Given the diversity of feedback mechanisms and different conditions of studies it is not possible to give an average level of achieved energy savings. The reduction rates are always dependent on a set of variables like the feedback medium, frequency, or design, as explained in the previous sections. Ehrhardt-Martinez (2010) ranged the achieved average savings from 4-12% of the baseline consumption, which is supported by most other studies (cf. the tabular literature overview in the Executive summary with average savings of 7-12%.

For an effective feedback design it is not only of interest whether savings are achieved and at what level the percentage savings are, but also whether these savings reflect a long-term effect by changing heating behavior and warm water routines for a longer time or whether these effects only occur for a short term. In the following, the results of some studies with a wider time-frame are reported:

- In Denmark, Nielsen (1993) tested enhanced billing for a period of three years. The 7-10% savings for single family homes stayed persistent over time.
- Ayres et al. (2013) also tested enhanced billing with a study duration of one year. The savings ranged from 2.1% to 2.5% and were even found to increase over the twelve month study period.
- In Norway, Wilhite and Ling (1995) also tested enhanced billing for a period of three years, with the result of 7.6% energy savings after the second year and 10% after the third year. Here the savings also increased over time.
- Daily and weekly feedback was studied by Staats et al. (2004) for the duration of three years. The savings resulted in around 7.6%. Here the energy savings also increased from 4.8% at eight months to 7.6% at two years and persisted long after the intervention was ended.
- The Massachusetts PowerCost Monitor Pilot Program (Siems, 2009) with its time-frame of 2.5 years examined the effect of real-time feedback. The overall reductions of 6.5% savings per household remained persistent and did not decrease over time.

But there are also exceptions to this tendency of persistence:

- Van Houwelingen (1989) tested real-time feedback for a period of two years. The results of 12.3% savings diminished after the energy monitors were removed. Apparently, no long-term change in behavior took place.
- In an NSTAR pilot program (Opinion Dynamics, 2008) a real-time display was tested with more than 3000 participants. Within the first six months, more than 1000 had stopped using the monitor. The main reason was the perception that the device did not work well.
- This is in line with the results found in a pilot study of the Energy Trust of Oregon (Sipe and Castor, 2009). Here, 34% of the participants stopped using the device within a few months.
- Van Dam et al. (2010) also recognized the decreasing effect of a real-time monitor on savings after some months (7.8% savings after four months, 1.9% savings after 15 months).
- Houde et al. (2013) tested real-time feedback information in a study covering nine months. They could observe a decrease in savings after four weeks.

Even though it is difficult to draw a general conclusion from the diversity of studies, most feedback information resulted in long-term savings, and sustainably reshaped consumer behavior and routines. Ehrhardt-Martinez (2010) reviewed 28 feedback studies that included information about the persistence of savings and found that in 20 of these studies (73%) savings either remained constant or increased.

Only in cases of a real-time display, which requires the technical interaction und management of the device, sometimes a high number of consumers stopped using the feedback system.

Darby (2006) reviewed various billing programs in the Nordic countries, and found that the longer the duration of a study and the more feedback information is given, the more persistent the savings are.

4.4 Accounting for consumer heterogeneity

Since it was shown above that many saving effects are persistent over time, we will now answer the question of whether the measures of feedback information are effective for the wide heterogeneity of energy consumers – in other words, whether the savings are achieved by a high number of households or whether they are rather an exception than the rule.

The results in Schleich et al. (2013) from field trials comparing two types of feedback (web portal vs. postal billing) revealed savings of around 4.5%, which represent 154 kWh of saved energy per year. The 90% confidence interval ranged from 39 kWh to 270 kWh. Here the feedback effects are statistically significant for the 30th to the 70th percentiles. For households below the 30th and above the 70th percentiles, feedback appears to have no effect on electricity consumption. Thus, the savings are achieved by part of the consumers, so that in this case feedback does not affect the full spectrum of consumers.

The same conclusion holds for the results of Van Dam et al. (2010), who conducted a 15-month pilot study (2008–2009) in the Netherlands, testing the effects of home energy monitors. Saving results were measured after four months and at the end of the program after 15 months. Besides the finding that the effect of the real-time display diminishes after time (see Section 5.3), the variation of saving effects among participants (*n*=54) was substantial in both cases. After four months, achieved savings ranged from -35% to +45% with a standard deviation of 13.8%, and after 15 months, savings ranged from -45% to +30% with a standard deviation of 11.8% (see Figure 5).

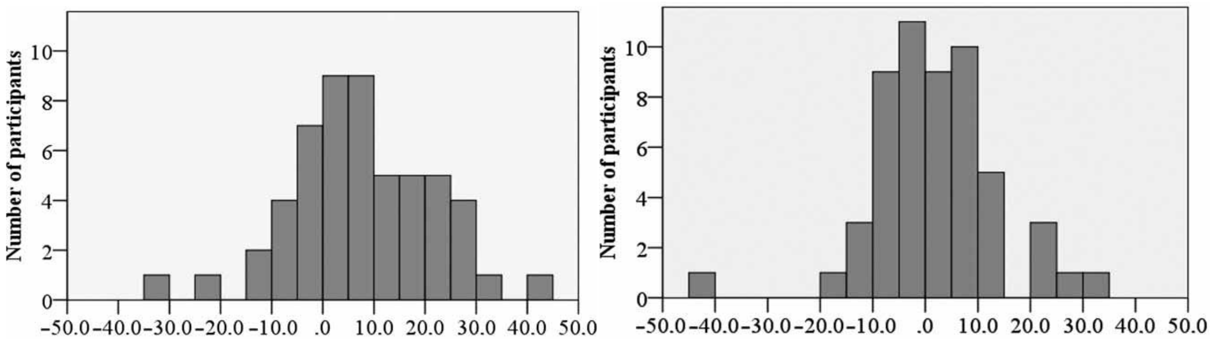

Figure 5. The distribution of achieved savings (%) after four months and after 15 months

Parker et al. (2010) tested an energy monitor in 17 households in Florida from May 2005 – April 2006. The average savings amounted to 3.7 kWh/day or 7.4% of the baseline consumption. Within the group, savings varied considerably, ranging from an energy increase of 9.5% to a savings rate of 27.9%. The distribution is shown below (Figure 6). In this case a general effect was not shown either.

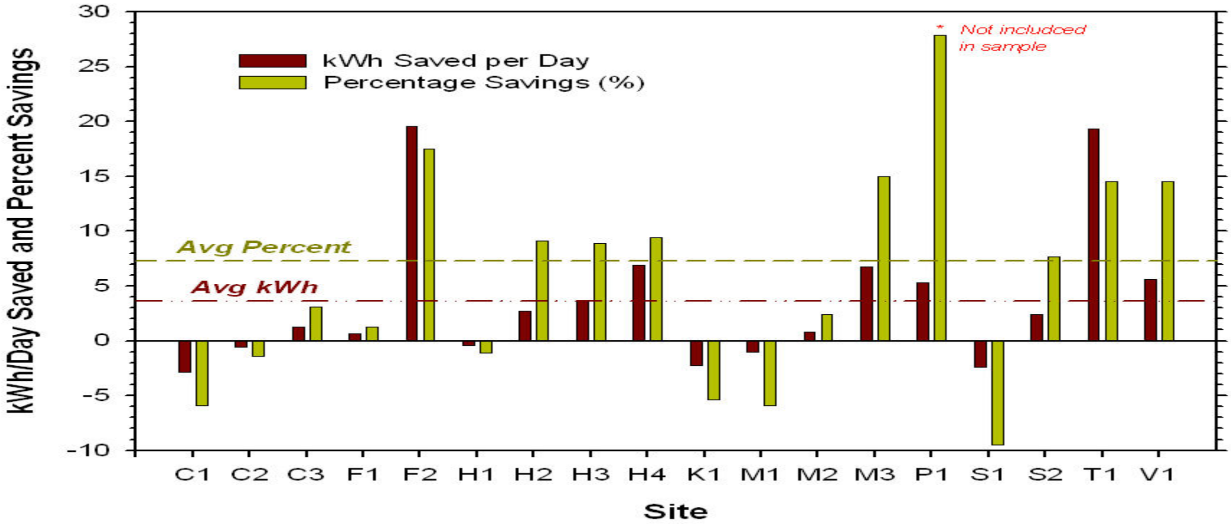

Figure 6. Measured daily electricity savings, in kWh and percent by site

EPRI (2009) summarized studies and indicated that saving rates differed within four main categories that can explain variation: age (younger households save more), income (households with a lower income save more), education (conservations are higher in more educated households), and historic consumption levels (the higher the baseline consumption, the higher the savings).

Furthermore, Winkler and Winett (1982) performed a meta-analysis on behavioral residential energy conservation studies using feedback in which effects were reported by different household income levels. They found a relationship between energy behavior resulting from feedback and the proportion of the household budget used for energy (electricity or natural gas) needs. This analysis concluded that feedback had little effect in reducing energy consumption in households where energy costs were no more than 2% of the household budgets. By contrast, people using a larger proportion (> 2%) of their income for energy were likely to benefit more from a feedback program (Farhar and Fitzpatrick, 1989). In other words, the more money consumers spend relatively for energy, the more they are inclined to relieve their pockets and reduce their spending by saving energy.

Brandon and Lewis (1999) conducted a study with 120 households in the U.K, who monitored their energy consumption over a period of nine months. To cover the heterogeneity of the population they picked households that represent different age structures, household sizes, and building tenures. This resulted in a large standard deviation with in total no significant saving effects. Applying a multiple regression, the most influencing variable on saving effects appeared not to be income, age, number of occupants, or tenure, but the variable 'environmental beliefs'. The amount of variance explained by this model was statistically larger.

Davis (2011) tested several feedback measures that can be implemented at minimum costs in order to influence the energy behavior of households. The measures consisted of peer comparison by sending households a graphical comparison of their consumption over the previous billing period to that of an 'average neighbor' (average consumption of 100 nearby households) as well as an 'efficient neighbor' (representing the 20th percentile of the same sample). Achieved energy savings were around 1.8% ranging from 0.9% to 2.9%. In this study, there was also a significant heterogeneity within the sample. However, the observable data could not explain the large variation. Even baseline usage, which is in many studies suggested to be the main driver of heterogeneity, could not explain why different households respond so differently to the treatments.

Houde et al. (2013) tested real-time information feedback with an average reduction of 5.7% in terms of savings. They tried to explain the heterogeneity of savings within the sample by testing a wide range of variables, covering demographics, housing characteristics, and psychological variables. This study also could not produce any evidence that the household characteristics explain the heterogeneity of the saving effects.

A summary report of the Electric Power Research Institute (EPRI, 2010) examined world-wide feedback studies being published over the last years. It compared the relatively low savings of 1-3% for monthly or quarterly feedback information with the higher savings of 5-10% for real-time information, and instantaneously stated that only a very small fraction of the population (5-10%) is receptive for real-time feedback. It further noticed the remaining uncertainties about how different subpopulations respond to feedback mechanisms. With, e.g., an average rate of 5% savings, it is still unknown why some subgroups reduce their energy consumption while others maintain or even increase their consumption.

To sum up, while there are some studies with a low standard deviation of achieved savings, most reveal high heterogeneity in savings due to varying characteristics within the household population or study conditions. Even though examining diverse variables, it was not always possible to identify the cause of differing saving results. Some might be attributable to the feedback mechanism and others might be due to household characteristics. In previous studies, it was not easy to clearly identify the diverse influencing variables.

Furthermore, it must be kept in mind that many study results refer to participants who voluntarily took part in the study and do not include those who dropped out. Such sample selection bears a certain risk of over-estimating the energy savings. Especially for long-term programs, the number of participants is often constantly decreasing. Taking the Helsinki experiment as an example (Arvola et al., 1999): From the starting pool of 926 voluntary participants one third dropped out and the pool decreased to a number of 696 participants at the end of the project.

4.5 Barriers of acceptance

After assessing that most studies reveal high heterogeneity in terms of achieved savings, the reasons why feedback measures apparently do not work for some consumer groups will be discussed in the following.

By reviewing a number of studies, Fischer (2007) found that the main barrier for the acceptance of feedback systems is the overload of information. Too many tools attached to a real-time display or an overload of additional information on a bill may complicate the situation for the consumer and lead to reversed effects. Furthermore, Fischer found out that specific additional information like social comparison can end up in an increase of consumption especially for low consumption groups.

Using interviews and a survey, Egan (1999) searched for the best graphical representation of feedback information on a bill. He found that even if consumers were able to understand the graph in the optimal way, this knowledge did not necessarily lead to adequate energy-saving actions. This is a hint for the necessity of concrete saving tips besides pure consumption information.

Ehrhardt-Martinez (2012) also examined barriers for taking action and found the high investment costs for insulation or the purchase of new energy-efficient appliances as a main reason for stagnant energy savings.

The Massachusetts monitor program (Siems, 2009) revealed the difficulty for a high number of consumers to deal with the technically rather complex real-time display. Starting with problems of installing the device, almost half of the participants had the perception that the technology did not work well. Similarly, the study of Allen and Janda (2006), in which a continuous feedback device led to no conservation effects at all, found the reason for this in the not very user-friendly display. Consequently, the participants ignored the device due to its complexity instead of exploring it or using the manual.

Summarizing, Duscha et al. (2006) found four categories of barriers: informational, individual, social, or financial barriers. Informational barriers often appear when feedback information is presented in a non-concrete way (e.g. just the consumed kWh). Individual barriers are related to household characteristics such as ecological awareness, willingness to change habits, and trust with the execution of energy-efficient measures. Social barriers can be found in accepted norms or power structures within the household itself, in its neighborhood, and in the entire society. Financial barriers occur when the investment costs of energy-efficient measures seem to be too high because long-term savings are not considered by a household calculating "in small periods". Furthermore, households rather take no financial risk due to unknown future developments. This is depicted in Figure 8. Based on these identified barriers a feedback mechanism should be designed to avoid predictable failure.

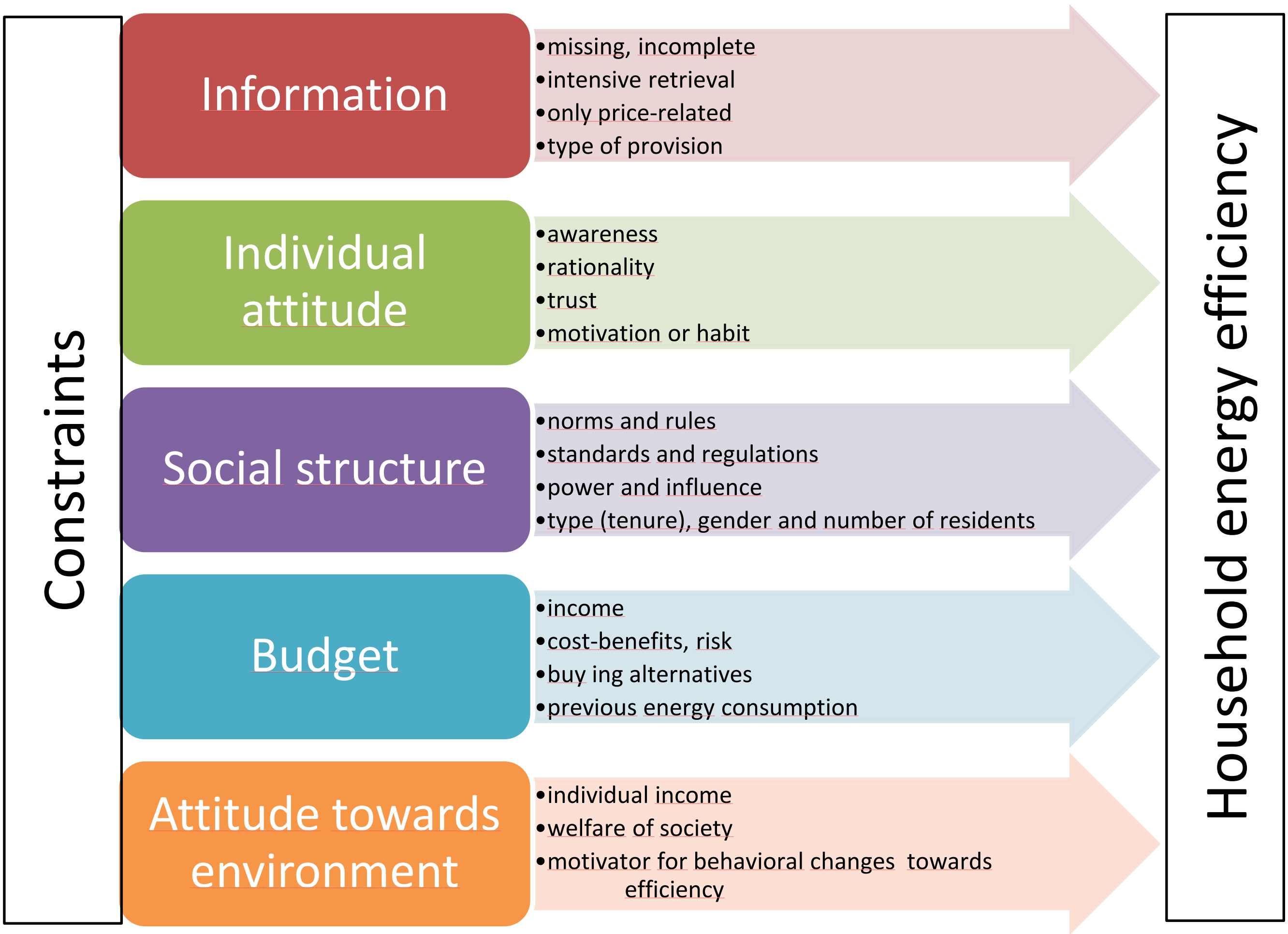

Figure 7: Inhibiting factors for household energy efficiency (Source: based on Duscha et al. 2006, modified and extended)

5 Conclusions

This study reviewed the scientific literature on feedback about energy consumption and its effectiveness on user behavior under varied design and frequency. In this concluding section we summarize the findings to the research questions (RQs) defined in the introduction.

1. **Which type of communication is particularly well suited for inducing behavioral change amongst final consumers?**

The literature suggests that the feedback medium is not very influential on user behavior (Section 3.4), which means that cost considerations and user preferences may be decisive.

2. **What is the optimal frequency and what is the optimal granularity of consumption and billing information?**

Literature on the influence of feedback frequency on user behavior is scarce and indecisive (Section 3.5), but the main tendency seems to be a positive correlation between frequency and effectiveness, with exceptions due to certainconsumer groups (cf. RQ 6) and design issues (cf. RQ 7).

3. **Which additional information can support behavioral change most, and which kind of change is achieved?**

On the one hand, many features can in principle improve the effectiveness of feedback (Sections 3.4, 3.6, and 3.7). These include the graphical representation of information with or without displays (i.e. electronic or paper-based), the underlying structure or architecture, historic comparison or comparison with similar households, specific energy saving goals, and advice on possible changes in behavior or equipment. On the other hand, users are vulnerable to information overload (cf. RQ 7), so a careful balance should be struck in the design process.

Different types of feedback lead to different behavioral reactions (Section 4.2), e.g., the more frequent (and therefore more detailed) the feedback, the more specific and application-oriented the reaction. For low-frequency feedback measures, additionally specified energy-conserving tips are necessary.

4. Is there any difference between consumption information and (additionally provided) cost information?

There is controversy in the literature on the effectiveness of monetary feedback: its inclusion could either have positive or negative effects (Section 3.6.3).

5. How large are the achievable saving effects (short term, long term) by user and real property category?

Average savings are in the range of 7-12% of the baseline consumption (Section 4.3), where reduction rates are simultaneously dependent on feedback medium, frequency, and design. Many studies find persistence of savings over time, with exceptions due to several causes (cf. RQ 7).

6. Are these saving effects achieved by only a few or a broad mass of people?

The literature indicates that effective savings are only achieved by part of the users, where some groups even increase their energy use after feedback. Studies explain the variation of effectiveness by age, income, education, baseline consumption level, energy budget, and environmental beliefs; still, the full heterogeneity has not been explained so far (Section 4.4).

7. Which barriers have to be considered regarding acceptance of final consumers?

Identified bottlenecks for the effectiveness of feedback are overload of information, lack of concreteness of behavioral change, investment costs, technical complexity, individual characteristics, and social structure (Section 4.5).

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