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Study of the efficacy of real-time energy display

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ABSTRACT

The main aim of the in-home energy display (IHD) is to make invisible domestic energy consumption more visible, by presenting households detailed and real-time (or near real-time) feedback about their energy use, which aids to control their energy usage and make savings on their energy bill. However, another significant benefit that households have to receive from using display is being able to read and manage information provided by this device. It is important that all display users, including older or people with sight disabilities, receive IHD, which they find easy to use. Therefore, IHDs should be designed in a way that provides the greatest benefits to all their users.

This thesis work focuses on the households awareness to energy use and on the reduction of energy demand through energy saving activities. To conduct the quantitative investigation, an in-home energy display interface for motivating effective energy consumption activities is designed, developed and implemented in participating households. The study investigates behavior change of end-users during whole period of using energy display. The results indicate that combination of real-time feedback, information and goal setting has influence on households' behavior. Household A modified their attitude towards effective use of home appliances and adopted some energy efficient habits. However, to achieve better results time period of experiment should be longer than it was. Because period of adaptation of energy conscious behavior in daily life takes some time to get used to it.
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Chapter 1 Introduction

Growth of world energy consumption caused increase of energy imports demand, exhaustion of energy resources and negative impacts on environment, such as greenhouse gas emission, change of climate and global warming (Lombard et al., 2008). Therethrough, nowadays efficient usage of energy becomes central topic for discussions. Significant percentage of the total energy contribution accounts for domestic sector. In 2010, EU householders consumed 26.6% of the total energy usage, this figure has stood between other two major sectors: industrial (25.3%) and transportation (31.7%) (Statistical pocketbook, 2012), the graph can be seen in the Figure 1.1. According to EuroAce (Janssen, 2004) householders mostly use energy for home and water heating (57% and 25%, respectively), for electrical devices and lightning (11%) and for cooking (7%).

![Figure 1.1 EU final energy consumption by sector](image)

Aronson and Stern (1984) consider alternative ways of energy conservation and argue that energy consumption can be reduced by providing customers with new established energy using behavior. Raaij and Verhallen, 1983 also state that one of the main determinants of the domestic energy consumption is householders’ behavior, and changing it can bring promising potential for energy saving. Therefore, with intention to reduce and enhance efficiency of energy usage, modification of end-users behavior in reducing energy consumption has to be taken into special consideration; users need to understand that their daily behavior has impact on daily energy use. To achieve energy conservation through changing user behavior, householders need to have comprehensive and real-time communication with energy usage (Chiang et al., 2012). Unfortunately, through current energy bills and energy metering house occupants receive limited, unclear and outdated information, e.g. amount of already used energy, rather than real-time energy consumption, which could be valuable in energy saving.

Employment of real-time monitoring and display technologies in energy consumption has better capability in providing user with feedback information, and so achieving energy savings. Boom in electronic communication technology now permits to develop such displays, used for
performing energy consumption information to householder for promoting energy conservation. Number of studies shows effectiveness of applying energy consumption displays, albeit results in reduction of power consumption were insignificant. For instance, Ueno et al. (2006) conducted monitoring project, which measured electricity and room temperature by Energy Consumption Information System (ECIS) developed and installed into the participated houses in Kyoto, Japan. Study has achieved only 9% of average reduction in energy consumption. Other study (Wood and Newborough, 2003) has led in the UK and involved 44 households, which used energy consumption indicators designed especially for receiving electronic feedback of energy consumption. The average reduction of energy use was 15%.

According to the Energy Demand Research Project, the problem could be in design of energy consumption displays, users can find display not intuitive, complicated in use or difficult to find information. Factors, as accuracy and type of presenting information (numerical display or analogue display) also can be a reason of small change in energy consumption (New perspectives, 2008).

Thesis research, described in the following chapters, focuses on the awareness of householders to energy use and on the reduction energy demand through energy saving activities. To conduct quantitative investigation, an in-home energy display interface for motivating effective energy consumption activities is constructed, implemented in participating households and evaluated.

1.1 Research question
The purpose of the project is to investigate and study the behavior of end-users in regard to receive feedback information of energy consumption to implement and demonstrate the design of energy display interface which aids to reduce domestic energy usage.

The main research question of the thesis project is the following:

Can the real-time displaying of energy usage information affect the behavior of household end-users with respect to their energy consumption?

In order to give comprehensive answer for the main question following sub-questions are stated:

1. How In-Home Energy Displays (IHD) can aid consumers in controlling energy use and spending?
   Knowledge about effective energy consumption can aid householders to reduce usage of energy, decrease carbon dioxide gas emission and save consumers’ money on energy bills. To achieve these benefits consumer should modify their energy conscious behavior, which can be realized by visualization of real-time feedback about their energy consumption, providing valuable information and motivational factors that encourage householders to save energy. Deployment of IHDs can be one of the advantageous solutions for visualization of domestic energy use.

2. What is a core specification for the real-time energy displays?
   Despite on variability of energy displays on current markets, purpose of using them is one: aid consumers to control their energy usage. This requires common specifications that should be included in all variety of energy displays.

3. How should the real-time energy consumption display be designed to provide user with better efficiency?
To achieve better results in energy saving interaction of consumer with energy display should be highly considered. It is important that all consumers, including elderly and disabled people, can easily use them. Therefore, IHDs have to be designed simple and explicit.

1.2 Thesis contribution
This thesis work focuses on the households' awareness to energy use and on the reduction of energy demand through energy-saving activities. To achieve benefits in energy conservation consumers should modify their energy conscious behavior. It can be realized by visualizing real-time feedback about their energy consumption, providing valuable information and motivational factors that encourage households to save energy. Using IHD is one of the solutions for visualization of domestic energy use. However, according to some studies not all IHDs currently available in the market satisfy requirements of the users. In the thesis work more effective in-home energy display with information that motivates to change attitudes towards energy consumption is designed and implemented in participating households.

The whole thesis work is divided into three main parts: (1) knowledge about effective energy consumption, (2) design and development of the in-home energy display and (3) evaluation of the IHD.

1. In the first part of the information that relates to effective energy consumption is analyzed. Number of studies are reviewed and researched to understand what knowledge is valuable in reduction of domestic energy use and what information can motivate households to save energy and need to be included into feedback that households receive through IHD. This information aids to improve households knowledge about effective energy usage.

2. Second part of the thesis work includes design of the IHD interface and developing of the software for measuring electricity consumption. For designing user-friendly interface random people of different age were interviewed about their preferences in energy display. For this purpose questionnaire that includes questions about design characteristics and features are prepared. Results aids to identify main requirements that have to be considered in design of energy display interface. Also attention is paid on the results of studies that analyzed efficiency of the current energy displays. And according to the combination of these results the interface of the IHD is built. Moreover, combination of knowledge in software engineering for implementing well-structured energy display, in programming and design for developing user-friendly program and in psychology for analyzing changes in households' behavior are used to build effective IHD.

3. The third part describes evaluation of the IHD. Three households participate in experiment, during which they use IHD and control their TV energy consumption. Results of the evaluation are analyzed and conclusion about whether households achieve expected results in reduction of energy use and changing their energy conscious behavior or not is presented.
1.3 Thesis organization

The thesis content is arranged as follows:

Chapter 2 performs overview of the state of the art, which comprises investigation of variety of research projects focused on designing in-home energy display for householders use.

Chapter 3 describes main knowledge regarding efficient energy consumption. Accurate and detailed information about energy savings would help to improve awareness of energy use among residence consumers. The information consists topics, such as conscious behavior and attitude to save domestic energy, motivational factors to encourage households use less energy, visualization of feedback to improve energy conscious of energy consumption.

Chapter 4 represents extensive information about in-home energy display and smart meter. Core specification and main types of energy displays, differences with smart metering and consumer preferences in display designs were analyzed in detail.

Chapter 5 includes information about important features and aspects in designing user interface of energy display. Information, such as main stakeholders, key drivers, functional requirements, description about involved hardware parts can be found in this chapter. In addition, questionnaire regarding households preferences in energy display features were described.

Implementation process and software design decisions, software architecture consisting patterns and layers are described completely in Chapter 6.

Chapter 7 depicts IHD deployment and experimental processes, which involve participants, monitoring process and overall testing results of the display.

In the Chapter 8 main conclusion of the thesis work is presented. Summary of the results of the whole research study and experimental session are described.
Chapter 2 State of the Art

Households are major energy contributors and remain as an important target group in energy conservation and in reduction of greenhouse gas emission. A number of studies (e.g. Aronson and Stern, 1984, Raaij and Verhallen, 1983, Geller, 1981) of the last decades focus on effective ways to encourage home inhabitants to reduce energy consumption. Majority of these studies (e.g. Verhallen and Van Raaij, 1981 and 1983, Martiskainen, 2007, McMakin et al., 2002) researched changes of households energy conscious behavior as an effective strategy for reducing domestic energy use. They state that it is important to consider both macro- (technological developments, economic growth, demographic factors, etc.) and micro-level (motivational factors, abilities, opportunities, etc.) factors that have impact on household’s energy consumption (Abrahamse et al., 2005).

W. Abrahamse et al. (2005) review 38 research studies and evaluate the effectiveness of interventions that motivate households to save energy. Studies are reviewed according to their field of social and environmental psychology and categorized by strategy type (goal settings, feedback, rewards, etc.). Providing households with feedback, especially frequent feedback, appeared as the most effective strategy and had better results in energy saving. And according to the studies (Stodulski, 2011, Costanza et al., Gyllensward et al.) that work on visualization of energy consumption the most effective way to visualize energy consumption feedback is to use in-home energy devices.

However, using feedback is not enough for receiving desired results, how feedback information is performed to consumers and how consumers understand the meaning of the feedback both are important aspects. Human-computer interaction needs to be taken into account, which directly depends on design of energy display interface. Therefore, the display technology and in-home communication architecture have to be designed to enhance end-users participation in energy conservation. In this context, variety of research projects has been focused on developing and designing electronic energy information display interface for households use. Few of these studies are considered and discussed in this Chapter.

Anderson and White, 2009 state that majority of the in-home energy displays (IHD) currently offering on the UK’s markets do not satisfy functionality and preferences of consumers, especially being critical to display design. During energy display design they suggest firstly consider both what kind of information and how this information has to be presented to end-users. Also designers have to take into account what effect they want to achieve on users’ awareness and behavior. According them, there are two types of goals in regarding the domestic energy display: short- and long-term. Short-term goals include immediate users actions, such as turning of the light and turning down the thermostat, which aid to achieve long-term goals: establishing habits and user behavior.

Moreover, this study (Anderson and White, 2009) comprises qualitative analyses of consumers’ experience of the electricity displays available on the market and determines key design principles and core specification that should be included in design of IHDs. During the study few different types of energy displays have been chosen and used by 38 participants during a week. All participants were divided into 5 groups according to their age and socioeconomic status (group 1: prepayment meter users, group 2: under 30 years old, group 3: 60-69 years old, group 4: 30-59
years old, socioeconomic group A/B/C, group 5: 30-59 years old, socioeconomic group D) and have been interviewed on their energy consumption knowledge. Then they discussed about the real-time energy displays and collectively designed few types of display interface. Energy displays, such as Wattson, Owl, Eco-eye, GEO minim and Efery Elite were used during the experiment, and according to the results the GEO display was closest to match all consumer specifications and had mostly impact on users behavior change.

C. Jacobs and M. Harnett (2011) also used different types of energy displays in their study. According to them, when designing in-home energy display great attention has to be devoted to consumers usability of the display. The main purpose of their work is to ensure that IHDs are designed in a way that end-users receive benefits from using them. They also emphasized that all end-users, comprising elderly and disabled people (sight problems, dexterity issues), should be able easily operate IHD. This is one of the important aspects of display design, because customer's ability of using the information, delivered by energy display, has impact on human-computer interaction and aids to better manage household's energy consumption.

During the study they determined IHD design attributes that can influence to ease the use of display. To do this, eight different IHDs, such as EnviIR, Ewgeco, Geo-Unifi, Eco-eye Elite, Navetas, have been chosen and features, as hardware characteristics, software and interface design, are investigated. According to these, there have been found a number of useful ergonomic design attributes, however, some of them showed poor usability features (e.g. Efery Elite: size of the graphs are too small to read an information). This study presents number of general design principles, which support good usability: explicit and readable text and graphics, backlights, intuitive icons, clearly divided zones of different information and large enough text and diagrams for comfortable reading. Experts also state that using traffic light system or audible alarm for representing current energy use and warning can be useful for customers (Jacobs and Harnett, 2011). For instance, including green, amber and red colours traffic light system indicates level of energy consumption. As for audible alarm, when consumption of energy is reached prescribed energy threshold, it makes a warning sound. thus save household's energy.

Another research (Chiang et al., 2012) shows that households, who used different types of display design with the same information on the screen, communicated with devices differently and did not accept the information equally well. In the study three prototypes of display design (numerical, analogue and ambient) were used and compared to find out what type of design is beneficially used by consumers. The role of color, accuracy and time response were also examined. The results of the study revealed that numerical design of display interface was more preferable (54%) and effective in performing energy usage information compared to analogue (32%) and ambient (34%) designs.

Wood and Newborough (2007) analyze how to better present the energy consumption information on the local and central displays in order to motivate consumers in better energy saving. During the investigation the following factors that influence on the design energy display interface are considered: display units (kWh, money, gCO2, etc.), display methods (numerical, graphs, diagrams, etc.), timescale (frequent/real time, hour, day, month, etc.) and recommendations on effectively visualization of the energy use information on both displays were given. For central displays, presentation of overall energy consumption during long period of time (month, year) can
reduce the energy use, and for local displays, indicating energy usage in money might be insufficient, due to the small financial savings.

In order to identify what are common factors and key aspects that characterise all studies researched in the thesis a summary table is created (see Appendix A). Particular attention is given to the following evaluation criteria: what behavior modification strategy (feedback, motivational factors, information, etc.) is used in the researched study, what type of interaction tool (Smart Meter, IHD, bill, etc.) they used, expected results, results that they received, findings during experiment, etc. It is appeared that the main common factors of the studies listed in the table are that all studies used feedback as modification strategy and send it via digital devices, such as IHD or SM. Experiment duration and number of participants involved in the studies are compared, most of them measured electricity consumption. Studies that used combination of behavior modification strategies, e.g. real-time feedback and goal settings or real-time feedback and information, were beneficial and reached significant electricity reduction (up to 22% and 15%, respectively).
Chapter 3 Knowledge of Effective Energy Consumption

Reduction of domestic energy consumption is particularly important, since energy demand of residential sector has risen significantly, unlike that of industrial sector. For this purpose, providing household members with valuable information that can lead to energy efficient choices can help to reduce energy consumption and carbon dioxide emission and decline the costs to consumers. Information should include knowledge of effectiveness of using feedback and visualizing it, motivational factors that encourage consumers to save energy and recommendations about changing energy conscious behavior.

The chapter covers all these valuable information that can aid consumers in energy conservation and starts from describing household energy behavior, because by modifying it consumers can reduce their energy use. It followed by sections, which include explicit information about feedback and motivational factors that can influence on consumers behavior and enhance their energy conservation.

3.1 Householders behavior on energy consumption

The values of energy consumption can differ vastly among householders, even with the similar house characteristics. Study (Roth and Brodrick, 2008) that was led in Florida involves 10 identical houses equipped with the same electrical appliances. However, collected energy use measurements show valuable distinctions, i.e. difference between the most energy consumed household and the least energy used residence was 2.6. The result obtained from this study is that participants’ behavior can significantly affect the domestic energy use, and by modifying it households are able to reduce energy consumption in residential sector (Roth and Brodrick, 2008).

Behavior is a sophisticated set of person’s emotions, habits, moral, social and normative factors, modification of which is a complicated task. Most of the energy consumption behaviors are adopted from consumers’ habits and daily routine (cooking, watching TV, using lights), which could be changed by adopting new energy conscious behavior and by increasing energy awareness. Measuring units (in-home energy displays, smart meters, enhanced billing) can aid households to be more energy efficient, and thus influences on their behavior (Martiskainen, 2007).

Van Raaij and Verhallen (1983) propose an overview of the behavioral model of household energy usage and examine relationship between groups of variables (see Figure 3.1). The purpose of the model is to gather and structure the determinants of domestic energy consumption. The core two groups: energy use and energy-related behavior (described in detail in section 2.3.1) are considered mostly.

Following factors that are depicted in behavioral model (see Figure 3.1) have a/an direct/indirect impact on energy-related behavior, and so energy use (Van Raaij and Verhallen, 1983):

- **Home characteristics**, as number of rooms, type of insulation, double glazing, wind exposure, has an impact on households’ energy behavior, thus, households’ energy use. There exist interactions between home characteristics and behavior of residence or consumers’ behavior may increase/decrease the home characteristics effects.
- **Energy-related attitudes** refer to behavior, but the attitude that generates behavior is not always true, i.e. if consumer has moderate behavior towards energy conservation, in all
likelihood he/she creates energy-saving attitudes. However, energy-saving attitudes do not always bring energy conservation behavior. Behavioral model (Figure 3.1) depicts four factors that mediate between attitudes and behaviors: acceptance of responsibility, energy knowledge, perceived effectiveness of one’s contribution and cost-benefit trade-offs.

- **Household lifestyle** includes personal variables (can influence on energy-related attitudes and behaviors), social-cultural factors, family life cycle (age, marital status, family size), personality values, such as interests, opinions (can cause actions to use more or less energy). Household income, employment and educational level also refer to energy use.

- **Energy price** plays significant role in household energy use and holds three main aspects: knowledge, price elasticity and feedback mechanism. Majority of consumers’ knowledge regarding energy price is poor: they pay monthly advance bill (gas, electricity and water) for estimated standard amount and annual settlement to correct for actual use, which confuse energy use and cost, so brings lack of price knowledge. The highest price elasticity refers to middle-income households (0.18), compared to low-(0.12) and high-income (0.14) households (Van Raaij and Verhallen, 1983). Effectiveness of feedback mechanism will increase, if time interval between energy use and payment is decreased. Useless feedback mechanism is annually received energy bill, i.e. interaction between payment and consumption is almost nothing.

![Figure 3.1 Behavioral model of energy consumption in residential sector](Picture was made according to Van Raaij and Verhallen, 1983)
The model illustrates interrelationship between five factors that are given in circle: (1) general information (energy problems: energy supply, car and appliances energy inefficiency, etc.), (2) specific information (energy cost, energy use of specific behaviors, etc.), (3) subsidies and energy prices, (4) building and design requirements and (5) feedback (detailed explanation is given in section 3.2). It is seen that general information has the longest path to energy use, so has the lowest impact on it.

3.1.1 Energy use and energy-related behavior
Household energy use is a dependant variable and directly influenced by energy-related behavior, which includes three types of behavior (Van Raaij and Verhallen, 1983):

1. *Purchase-related behavior* considers energy characteristics in purchasing durable household goods, as stove, air conditioning, heating system or dishwasher. Energy label is one of the energy characteristics that plays significant role in reducing energy consumption of appliances and has positive impact on consumers' choices on energy-efficient equipments. However, some studies argue that energy label slightly affects customers' choice, unless salespersons explain and highlight energy labeling. Kallbekken et al. (2012) researched that providing information, which makes lifetime energy cost more attractive to buy, brings increase in purchasing more energy-efficient products. The study includes three treatments: “lifetime energy cost”-label, training of sales stuff and combination of both and two type of home devices: fridge-freezer and tumble drier. For fridge-freezers, there were no essential effects, however for the second appliance, reduction in average energy use of sold tumble driers were in combined treatment (4.9%) and training treatment (3.4%).

2. *Usage-related behavior* interacts much closer with behavioral patterns and habits, so, changing this is more difficult. It consists of day-to-day energy behavior of using thermostat and ventilation system, while purchase-related behavior concerns one-time investment behavior of energy conservation. Verhallen and van Raaij (1981) studied energy-related behavior of 145 households in the Netherlands with respect to home heating. Household behavior explained by energy-related attitude of home occupants, house characteristics, socio-demographics and special circumstances (absence from home, illness, etc.) and analyzed according to six components: bedroom temperature at night, home temperature during absence and presence, curtains and bedroom use, airing out rooms. All these factors refer to 26% of the variance in household behavior.

3. *Maintenance-related behavior* is a type of behavior that refers to maintain home appliances and heating system and comprises of services, repairments and insignificant home improvements. It is relevant for future research on domestic energy savings. Research on this field is essential for new types of energy producing and conserving technologies, such as solar panels, wind turbines, energy-efficient furnaces. Stern and Gardner (1981) suggest that for energy conservation consumers have to think about investing money in energy efficiency and renewable energy development (purchase- and maintenance-related behaviors), which would involve changes in householders behavior and social psychology.
3.1.2 Recommendations on energy efficient behavior

As discussed in previous sections there exist a number of economic, social and psychological factors that have impact on energy consuming behavior of householders (Martiskainen, 2007). But under which conditions households are more likely to adopt their energy conscious behaviors. McMakin et al. (2002) analyze and propose several recommendations that aim to modify energy saving behavior:

- Households should see energy efficiency as a benefit to them, not as a cut down.
- It is important to visualise energy use and saving and add goals and motivations.
- Information should be displayed distinctively and in an individual format.

Moreover, they emphasise the fact, if adoption of behavior is easy and residence has all skills/resources for using it, household will change behavior.

Considering energy-related behavior, Van Raaij and Verhallen (1983) suggest to pay attention on energy contingency, which also has impact on households behavior, thus, energy use. Study considers two noticeable aspects of energy contingency: ventilation and heat production, and based on them defines five energy-related behavioral patterns: conservers, spenders, cool, warm and average. The difference (in social-demographics and attitudes, routine) between the behavioral patterns are significant, e.g. average variation between conservers and spenders is the largest (31.5%). Therefore, this needs the implementation of different strategies to change households behavior with respect to energy conservation. The conservers (low temperature, low ventilation level) characterized as high educational level, small family size and lowest energy users, and according to research this pattern represents desired behavior and energy use. In opposite, spenders (high temperature, high ventilation level) have lower level of education and spend more time at home. Their energy use is higher compared to other patterns. Suggestions that were given to spenders are to lower thermostat settings, ventilate less and insulate home, however, changing energy behavior of this pattern stays as a difficult task. Energy use of cool segment (low temperature, high ventilation level) is medium. They are suggested to consider use of ventilation system, e.g. decline level of ventilation or heat recovery. Warm segment (high temperature, low ventilation level) includes mostly older people and their comfort preference is higher compared to other segments. Comfort here is related to high temperature. The energy use of this segment is also medium. behavioral recommendations are to reduce home temperature and warmer closing. The average segment considers individual differences in summertime. This segment can be more energy effective, if emphasizes on reducing temperature and ventilation level.

3.2 Feedback on household energy consumption

Feedback plays important role in increasing customers' energy awareness and brings about 10-15% of energy use reduction (Stodulski, 2011). According to Oxford English Dictionary feedback is defined as following: “... the modification or control of a process or system by its results or effects; information about reactions to a product” (OED, 2013). So feedback is a process in which involved information of past or present can have influence on present or future results (Feedback def., 2013). Focusing definition on domestic energy consumption point, further feedback is going to be defined as residence sector-specific energy consumption information. Neenan, 2009 identifies types of feedback and categorises them into two groups: indirect feedback and direct feedback. All types
of feedback are depicted in Figure 3.2 and ranged from 1 to 6. First four types of feedback represent indirect feedback, and last two include in direct feedback.

![Figure 3.2 Feedback types (Picture is taken from Neenan, 2009)](image.png)

However, Darby in her study determines three types of feedback to householders: direct, indirect and “inadvertent” (a result from social, technical or household changes) feedbacks and reviews each of them on effectiveness.

Effectiveness of feedback together with success of smart metering, energy management and home automation technologies strongly depends on consumer acceptance and participation. To enhance consumer participation and consumer satisfaction the following needs to be considered (Ehrhardt-Martinez et al., 2010):

- Convey consumers with number of non-financial motivational factors, such as competitions, goal settings and special events.
- Encourage partnerships and endeavors between utilities and third-party providers to raise household engagement and product innovation.
- Motivate households to change habits, behavior and attitude towards energy consumption and apply appropriate technology. Effective energy savings comes from conscious energy use behavior, but not investments.

### 3.2.1 Direct feedback

Direct feedback provides energy usage information about the real-time of consumption or close to real-time consumption (Ehrhardt-Martinez et al., 2010) and includes the following two types (Neenan, 2009):

- **Real-time feedback.** The most common delivery mechanism for real-time feedback is the energy or in-home display, is becoming popular among utilities and their regulators. In
general display shows household’s total energy consumption in real-time (or close to real-time) and corresponding cost.

- **Real-time plus feedback.** This type of feedback allows the consumer to monitor not only overall house energy consumption, but also view and control usage of individual home appliances via area networks.

According to Darby’s investigations direct feedback is the most productive and effective type of feedback: up to 20% of energy savings were reached by engaging various interactive cost- and power-display appliances.

Houde et al. say that applying real-time information feedback achieves 20% of decrease in domestic energy consumption. However, access to feedback conducts an average reduction only for 5.7%. The study focuses on estimation of the impact of providing real-time electricity consumption feedback to households. The feedback technology includes a monitoring appliance (to record electricity usage) and a web application (to display used electricity information in real-time). Web interface was produced by Google and called Google Powermeter and it shows main feedback feature: the graph that presents 10 min interval and historical data of electricity use.

### 3.2.2 Indirect feedback

Indirect feedback is a type of consumption information that is provided after energy use. In Figure 2.1 four types of indirect feedback are depicted: standard billing, enhanced billing, estimated feedback, and daily/weekly feedback (Neenan, 2009).

- **Standard billing.** It is a simple and traditional type of bill, which receives residence, displays monthly energy usage (kWh) corresponding cost, rate ($/kWh), etc.
- **Enhanced billing.** This type of feedback represents more information than standard billing: household’s consumption pattern and some comparisons, such as comparisons of previous month’s usage with current month consumption.
- **Estimated feedback.** This category includes statistical techniques to estimate overall home energy usage based on resident’s house type, billing and devices data. The feedback is delivered as energy report for one time or continuously.
- **Daily/Weekly feedback.** It uses measurements of current energy consumption that is collected by a utility or third party and presented to the householder through the web, email, or mail-reports.

Majority of current feedbacks that are available to residential customers are simple indirect feedbacks, which are provided by utilities. The effect from these feedbacks is very low and has no motivations to householders in energy conservation. Darby gives as an example for indirect feedback, the study of Garay and Lindholm, which was carried within 15 months, during which energy usage were measured, and bills with historic and comparative feedback were delivered to participants. However, resulted with no savings, but get 96% of customers’ satisfaction.

### 3.2.3 “Inadvertent” feedback

“Inadvertent” feedback provides possibility for learning applying situations and novel technology. Darby considers only three studies regarding this type of feedback. First study involves cable service that comprises of combined energy information to the householder, automatic meter reading, load control by the utility and time-of-use pricing, and was provided to about 600 electricity customers. Experiment shows significant results: 7-10% of average bill savings and 2
kWh peak demand energy decrease in each residence. Inadvertent feedback’s future possibilities can be development of community energy conservation projects, with their potential for social learning.

### 3.3 Motivational Factors

Information alone does not appear to be sufficient to achieve desired reduction in energy consumption, not all will act on the received information. People need strong motivations. Therefore, motivational factors play an important role in energy conservation, which can have influence on energy use behavior of a consumer, and so have to be taken into account in displaying energy consumption feedback. Wood and Newborough (Wood and Newborough, 2007) in their study identify and discuss the factors that could encourage consumers to change behavior in energy conservation. Motivational factors, such as self-comparison, self-set goal, tariff, competition with others, social and monetary rewards were divided into three groups:

1. Basic comparisons
2. Goal settings
3. Rewards

However, efficiency of motivational factors depends on individual and his/her viewpoint. Therefore, in a process of designing energy display it is necessary to include positive as well as negative information, i.e. shows not only desired results of decreasing energy consumption, but also give information of any energy expenditures.

#### 3.3.1 Basic Comparisons

Displaying comparative information of energy consumption is one of the ways to motivate householders to create conscious behavior with regards to energy saving. Types of comparisons are listed as follows (Wood and Newborough, 2007):

- Appliances comparison
- Rooms/zones comparison
- Self-other comparison

Appliances comparison is the most effective and basic type of comparison, which is applied by the most of energy displays. Consumers read and compare energy usage information of domestic devices (TV, lightning, dishwasher, etc.) and decide towards which appliance they would employ energy saving efforts, e.g. householder sees information that lightning energy expenditure is higher than TV’s expenditure and starts to use less lightning than before, thereby, changes his/her behavior with respect to energy conservation. However, in case of receiving comparison information about space heating, lightning and TV simultaneously, heating would exceed energy consumption than other devices, so householder may decide that energy saving activities towards to other devices (lightning and TV) are not efficient. Similar results can be viewed in rooms/zones comparison, majority domestic electricity consumption is taking by kitchen, so in comparison of kitchen with other rooms, pays attention only to kitchen then other rooms.

Jensen (1986) suggests to consumers to lower energy use, they must be involved in comparison process and must have some standards or goals to be able to estimate the received energy consumption information. He analyzed the comparison process as two separate processes: self comparison (comparing present consumption feedback with previous consumption figures) and social comparison (comparing own consumption levels and behavior with others’ usage
feedback and behavior). Consumer, provided with current and previous consumption feedbacks, is involved in self comparison process. In this process, performance of previous energy usage is applied as a standard, which the customer compares to current feedback and, hence, behaves to reduce future energy consumption. In social comparison process consumer, received present usage feedback with current usage figures of his/her neighbor, acts towards energy saving using neighbor’s usage feedback as a standard. Experiment that was presented in the study shows reduction of energy consumption engaging both self and social comparison (13% and 23% respectively).

3.3.2 Goal Settings
Satisfaction of achieved goals can trigger consumers to be more energy efficient. However, aspects, such as target level have to be taken into account, e.g. easily achievable goals may be less effective than difficult goals. Harkins and Lowe (2000) report that the investigated 400 studies gave the same results in goal settings (self-set, set by an external source): participants who received specific and difficult goals gave more effective performance compared to instructed participants to do their best. The meta-analysis of the study presents that self-set goals can cause goals setting effects, but under two conditions: (1) before setting goals participants need to partake in pretest equal in time period with experiment; (2) test conductors need to have access to participants’ goals and performance.

Consumer can set goals internally or manually. In internal case, householder can set himself/herself goal that this period he/she consumes less energy compared with previous period of time (week, month, etc) or aims to use up to certain amount of energy in given period. In the second case, householder can set desired saving goals into energy display, e.g. consumer’s goal is to achieve the 20% of energy reduction or $50 savings by end of the year can be programmed into energy display and by visualizing it consumer would carry out efficient energy conservation behavior (Wood and Newborough, 2007). The study (McCalley and Midden, 2002), was conducted in the Netherlands, it analyzed the role of goal settings in energy consumption and represents experiment on comparison self-set and assigned goals to find out which of the two goals is most effective in energy conservation. Participants received feedback through washing machine control panel set with saving goals. The study came to the results that both goals, self-set and assigned, succeeded in energy reduction (21.9% and 19.5%, respectively).

3.3.3 Rewards
Monetary reward is one of the strongest incitements in performing sufficient results of energy saving, which comprises of two types: direct payment to save energy and budget savings from energy conservation or peak demand reduction (Wood and Newborough, 2007). Midden et al. (1983) represent the effectiveness of financial reinforcement for decreasing the energy use. The study involved 91 households and tested the effects on electricity and gas conservation of four strategies: individual feedback (consumer previous energy consumption feedback); comparative feedback (consumers’ energy use feedback in comparable situations); monetary rewards in case of energy conservation and general information of energy savings. Results show that compared to individual and comparative feedbacks monetary payment has the most significant impact on decrease in electricity use (19.4%).
Emotional reward (e.g. social commendation, receiving positive feelings) also can be a good reason for reducing energy consumption. For instance, consumers, see on an energy display indicators of reduction of greenhouse gas emission due to their energy conservation, and can feel themselves as positive persons and good environmentalists for both society and for nature. Jensen et al., 2012 state that environmentally friendliness and responsibility have potential in encouraging people to change behavior with respect to energy conservation.

3.4 Visualization of energy consumption
For the purpose of better managing domestic energy use, it is important to emphasize visualization of energy consumption feedback, which allows households to monitor and understand their consuming energy data. Consequently, it leads to concrete activities regarding energy efficiency. Solution for visualization of energy use can be deployment of smart meters and in-home energy displays, which can represent the real-time energy monitoring, cost operation and the amount of carbon dioxide (CO2) emissions in an attempt to motivate users in energy conservation (Costanza et al.). Researches discussed in Section 3.2.1 also state that visualisation of direct feedback (real-time energy consumption information) to households achieves valuable savings in energy consumption (up to 20%).

Gyllensward et al. confirm that by visualizing energy consumption of different appliances, household can learn energy consuming information of each home equipment and be motivated to conserve energy. They designed prototype of electrical radiator that visualizes energy and emits heat only from light bulbs. 35 bulbs were attached in metal frame between two panes of glass and have sensors for measure a room temperature. The device was tested by ten participants and their opinions and experience were discussed. Most of the participants found that ambient display is aesthetically pleasing and using it is interesting way to present energy consumption.

Costanza et al. demonstrate the design, implementation and evaluation of visualization device that provides consumers with current and past energy consumption data and allows to control graphical energy measurements. The display was installed in 12 households and used by them during two weeks. The overall result shows that design was largely successful in engaging users (energy savings were 3-80%).
Chapter 4 In-home Energy Displays

In-home energy displays (IHD) are measurement units that provide households with real-time (near real-time) feedback on their energy consumption and allow them to behave with respect to energy conservation. In a current market there exist a huge variety of displays that can work in group with current electricity or smart meters, solar inverters or other home energy measurement systems (several types of IHD are presented in Section 4.2). There are presented few ways of measuring households’ energy consumption, which involve IHD (Sailwider, 2013):

1. **Uni-directional wireless energy monitoring system.** The system includes display unit, transmitter and sensor clamp (clip). Sensor clamp is fixed around the null/live line of electricity meter and monitors the magnetic field around the power cable to measure the electrical current passing through it. Then transmitter gathers the electricity consuming data via the sensor clamps. Consuming status and carbon dioxide produced by this used energy are displayed on LCD screen that, in general, can be located at any place in the house, since it works wirelessly with the power transmitter.

2. **Bi-directional energy monitoring and control system.** The main difference between previous monitoring system with bi-directional is that uni-directional system transfers signals from transmitter to the display only, and uni-directional system is able to transmit back and forth. The system consists of sensor plug sockets, are terminals for monitoring and controlling appliances, so every device connected via this socket can be controlled (turn on/off) through the system and display energy consumption of each appliance.

3. **Centralised electricity energy management system.** This system is more suitable for multi compartment buildings. Centralized system enables users (in the same LAN) to monitor and manage all energy usage from appliances on the computer. It comprises of three parts: (1) Management Software with user interface - electricity energy monitoring and control center; (2) Smart Collector for connection with PC via USB data cable, which collects data directly/indirectly from the smart terminals and send the center's instruction and settings to the smart terminals; (3) Smart Terminals, which are sensor sockets integrated with repeater function, establish a star network with itself (Sailwider, 2013).

Variety of studies have worked on pilot in-home energy display utilities and achieved important results in energy consumption. Van Houwelingen and Van Raaij (1989) designed in-home display for measuring gas consumption, which during test period achieved significant reduction in gas usage. The best result in decreasing gas consumption (12.3%) was in IND group, who use installed display and also receive advice about conservation.

Sexton et al. (1987) test energy monitors and investigate household response to these displays during time-of-use. User can activate the device features by pressing button, that include current rate of electricity use (cents/hour), summed monthly electricity cost, monthly bill and sum of the last bill. Moreover, display provides consumer with consumed electricity cost of any vast device in home or consumer’s activity. Reaction of participants to displays was various: 53% said that device is useful in energy savings, but only 31% of them agreed to buy the monitors. Overall results show that monitoring has no effect on consumer energy conservation, but achieve shifting of electricity use from peak to off-peak periods.
4.1 Specification
IHDS have to be designed properly, so households can benefit from using these home devices. It is important that all consumers, including elderly and disabled people, can easily use them. This requires common specifications that should include all variety of energy displays.

Represented here core specification for in-home energy displays is based on the outputs of the focus groups participated in the experiment (Anderson and White, 2009) that is mentioned above (see Section 1.1). Settings, as tariffs and time update automatically are a core assumption of the specification. As for minimum specification for IHD, energy displays should monitor general characteristics of all smart meter displays, however, display design should not be obliged only for them. It is possible that households after learning from their displays claim more features for monitoring, which have to be added with proper circumspection. However, in designing energy display firstly vividness and simplicity have to be considered.

Displays are divided into interactive and non-interactive and were analyzed separately to recommend personal specifications.

*Interactive display.* Interactive displays should comprise the following:
- Understandable gauge of real-time consumption
- Cost rate of consumed energy/gas for current state
- Numerical spending indicator for whole day
IHDP also should give information about the following features:
- Cost rate of each day for the last week
- Summarized cost rate for the whole last week
- Summarized cost rate for the whole last month
- Summarized cost rate for the entire quarter

Similarity of historic period and billing period should be contemplated for consistency of display to billing.

Energy displays should convey options of changing indicators, e.g. switch cost indicator to energy use rate, etc. Moreover, IHD needs to be portable and can be powered by inner battery and by mains.

*Non-interactive display.* In a case of loss intercommunication with device, display should include the following (Anderson and White, 2009):
- Vivid real-time energy/gas consumption indicator
- Cost rate of used energy/gas each day
- Indicator of entire day showing spent money of used energy/gas

If household uses alternative energy resources (solar panel, wind turbine), display should represent information regarding this generated energy (measures of production and consumption). Expressing used energy and gas in rate of carbon dioxide also can be valuable for consumers.

4.2 Types
In-home energy displays due to their feedback representation types can be classified into three categories (Darby): numerical, analogue and ambient display.

*Numerical or digital displays* present explicit and variable-based information regarding energy/gas consumption, which aids to consumers in fast reading and easy understanding monitored measurements. In numerical displays most measurements and measurements related
information are presented through numbers, which is important in learning monitored information (Chiang et al., 2012).

One type of numerical display currently available in the market is Onzo smart energy kit (see Figure 4.1) independent of installed metering technology, which includes: sensors to collect measurements, in-home display to monitor this measurements and web service for historic usage and tips. Onzo display conveys real-time information and stores synchronized copy of compressed data. The study that carried out to find out device effectiveness shows 8% of average energy use reduction and 5% decrease in peak demand (IHD Efficacy Report).

Figure 4.1 Onzo smart energy kit

Analogue displays represent consumed energy/gas information through graphs, charts, dials, column rates and bars instead of using numbers (Chiang et al., 2012). To determine accurate range of energy/gas measurements can be difficult on this type of displays, but difference between current and target ranges can be seen more distinctly. Analogue displays are sufficient in providing information of future states, e.g. give better visualization of how much time filling tank of fuel or heating room will take (Frankish). Also different types of information can be provided simultaneously by these displays, for instance, color classification of dial interface can present level of fuel in tank (green - full, yellow - medium, running out - red).

Figure 4.2 GEO
Several studies show the efficiency of analogue displays, investigating GEO device (see Figure 4.2). It is a car dashboard, which comprises analogue components, as speedometer. GEO makes accent on conveying the useful information, rather that data, and gives comparisons between current and target values through bars. The study (Anderson and White, 2009) discussed above, resulted that GEO display meets all specifications that were created during investigations and was preferred mostly by participants.

Ambient displays do not provide customers with detailed information as do numerical and analogue displays, instead present only overall situation. These displays use no scale or numbers of consumption, information is illustrated by using pictures, lights, colors, sometimes sounds. Nowadays types of ambient displays are variable: from artificial flowers, framed photographs, even robotic pets.

![Image of Energy Puppet in 'Normal mode'](Image)

Abdelmohsen and Yi-Luen Do (2008) in their study represent Energy Puppet ambient display, which produces various ‘pet-like’ activities towards energy consumption of home appliances to inform household members about their energy usage state. There are three types of behavior: ‘Normal mode’ - it rises arms, eyes are green (see Figure 4.3), ‘Medium mode’ - blue eyes and arms at the middle position and at ‘Too high mode’ puppet starts produce roar sounds, drop arms and eyes become red.

### 4.3 Integration with Smart Metering

Smart meter is the electronic measurement equipment, which provides consumers with energy consumption billing information and aids utilities to operate energy system (White Paper, 2011). Smart metering includes in Advanced Metering Infrastructure (AMI), which is an architecture for automated and two-way communications technology for information, monitor and control energy usage between smart meters and utility companies. The main purpose of the AMI is to provide utility companies with real-time energy consumption information and allow customers to use energy based on current energy price (WhatIs, 2010).

Capabilities of smart meters are following (Van Gerwen et al., 2006):

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● Possibility for registration of energy consumption in real-time/near-time and to generate electricity locally (e.g., in a case of photovoltaic cells)
● Ability to read the measurements both locally and remotely (on demand)
● Possibility to limit throughput of energy using meter (e.g., in a case of cutting electricity to the customer)
● It is possible to interact with premise-based networks and devices (e.g., distributed generation)
● Ability to read other households objects of utilities (e.g., gas and water).

Smart metering provides vivid and explicit information about consumed energy/gas to customer in different ways (see Figure 4.4) (ESMIG report):

Figure 4.4 Smart Metering: ways of providing information (Picture was taken from ESMIG report)

- **Better billing.** Energy/gas use information can be delivered to customers through more accurate billing system, which includes detailed measurements of used energy and target advice on efficient energy consumption.

- **On-line data.** Data regarding consumer energy/gas usage information can be provided by web site portals, where users can find their energy/gas usage information and carry out evaluation on energy saving investments.

- **Real-time feedback.** Using local communication interface consumer can view energy/gas use information directly from monitors installed in home. Data is provided in real-time or very close to real-time, so consumer is able to control of usage energy/gas by any home appliances by turning on or off. Measurements can be converted to currency or carbon dioxide rates to increase influence customer's attitudes towards energy/gas conservation.

### 4.3.1 Existing Smart Meter Studies

According to American Council for an Energy-Efficient Economy (Smart meter, 2013) nowadays 36 different types of smart meter and feedback programs for domestic sector are available around the world. Extensive research on the existing smart meter trials have been done and published valuable outputs. For instance, studies involved smart metering system with real-time feedback, which carried out in Europe, Australia and North America, have shown significant results in reducing energy consumption by households (up to 20%) (ESMIG report).

However, smart meter deployment program is not going well for all countries, e.g. in 2005 Oxxio, electricity and natural gas utility, proposed first smart meter (for energy and gas) in the Netherlands. Two years later Dutch government announced that all households should implement
in their houses smart meters by 2013, according to a national energy reduction plan. But, consumers raise privacy and security issues and in 2009 deployment of smart meter has become optional, rather than compulsory (Smart meter, 2013).

One of the smart metering studies (New Perspectives, 2008) presents results of two-year pilot test of smart meters for measuring fuel consumption. The main goal of the study is to produce quantitative and qualitative information on residences’ behavior and use of the smart meters, which were installed into 150 London households. Participants during the whole test period received personal feedback on their energy consumption and recommendations on energy saving. During experiment have been found that location of smart meters is significant, and households with smart meters placed in better visible locations five times more interact with their metering devices compared to residences with smart meters in less visible places. Moreover, consumers behave more energy efficiently: turn of lights and home devices, control space and water heating more carefully and start using energy efficient lighting bulbs. Household attitudes towards smart meters have changed during testing time: if at the beginning of experiment only 25% of users would recommend smart meters, than after a year this rate is doubled (50%). Consumers, who were controversial to smart meters decreased from 12 to 7%. However, at the end of the trial test results were not as expected: part of participants reduced fuel consumption (33%), and other half showed increase in fuel use (33%). These results might be caused by technical and internal communications problems that appeared during experiment.

4.3.2 Difference between IHD and Smart Meter

Despite the fact that the purpose of both in-home energy displays and smart meters is identical: measure energy consumption and monitoring it for consumers, they have some differences in comprising parts, implementation and communication. The following Table 4.1 determines some dissimilarity between IHD and smart meter (Energy monitors, 2013, Halo, 2010):

<table>
<thead>
<tr>
<th>IHD</th>
<th>Smart Meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>The most energy monitors display real-time electricity usage in units of energy used (kWh), cost or carbon emissions. Some have additional features, such as setting daily electricity usage targets or alarms to alert households when their have used a set amount of electricity.</td>
<td>Smart meters are high-tech electricity and gas meters, and replacement for current electricity meters. They measure exact gas and electricity usage and send all this information back to energy supplier.</td>
</tr>
<tr>
<td>IHDs mostly made up of three parts: handled monitor, transmitter and sensor</td>
<td>Smart meters consist mainly from advanced energy and gas measuring device (replacement for existing) and may also include display to show consumed measurements.</td>
</tr>
<tr>
<td>The most energy displays can monitor only one energy consumption (they cannot be able to monitor electricity and gas measurements simultaneously).</td>
<td>Smart meters can be used for monitoring electricity and gas consumption at the same time.</td>
</tr>
</tbody>
</table>
Energy displays can be installed in home by consumers themselves. Smart meters cannot be self-installed, i.e. it is connected directly to the mains supply, thus requires a professional setup.

Energy displays have no connection with energy suppliers, they present measurement data to consumers via display. Smart Meters are connected directly to the mains supply they provide information directly to the utility company.

<table>
<thead>
<tr>
<th>Table 4.1 Differences between IHD and Smart meter</th>
</tr>
</thead>
</table>

4.4 Consumers preferences on display interface design

Current digital displays for informing consumers about their energy usage, which exist in large variety, aim to control energy consumption and encourage residents to behave efficiently at the point-of-use. However, according to several researches, such displays achieve insignificant results (or no results at all) in domestic energy conservation (7% in Ueno et al, 2006, 15% in Wood and Newborough, 2003, no reduction in Sexton et al, 1987). One of the reasons can be inaccurate, unreadable and incoherent interface design of energy monitors, using which not all consumers are able to understand measurement information. Therefore, these display technologies have to be designed to enhance households’ participation in learning energy consumption and moderate their energy conscious behavior.

In designing display interface visual characteristics, facilities and the way how they are organized play significant role, which includes following features (see Figure 4.5) (Wood and Newborough, 2007):

- **Motivational factors** (they were discussed in details in Section 3.3);
- **Display units**: kWh, money, gCO2, environmental factors;
- **Display methods**: linguistics, numerical, pictorial, charts, graphs, tables, diagrams;
- **Time scale**: frequency/real time, self-specified, minute, hour, day, week, month, year;
- **Category**: activity/end-use, fuel, time, total cost, room, setting, person.

The display units can affect valuably on consumers energy usage, providing coherent and accurate understanding of energy use information. kWh is the most obvious and common type of the units in visualizing consumed electricity or gas, also gas can be viewed in volume unit (m³). However, most of consumers have difficulties in accepting and estimation these scientific units. Therefore, keep visualization of display units pretty simple, e.g. use symbols or simple graphs, for users’ understanding is the main point. Another display unit is money unit, which may include information, such as time-of-use cost tariffs and potential savings, could be also effective in energy savings. Wolsink (1997) analyzing energy consumption improvements, suggests that effort should be made to include monetary savings in tariff-system for achieving conservation. But more effective way to display monetary units is to show overall cost expenditure of domestic energy usage, rather than representing individual rates for each appliance in home, because money saving for each domestic device is nonessential, and will not motivate consumers to save energy. Including in display design units, as rates of carbon dioxide emission and other environmental units can influence on consumer understanding of energy usage. According to investigations of Mansouri et al. (1996) on social-psychological aspects of domestic energy use most households are willing to receive energy use information including environmental impact and to change their attitudes to save energy and reduce their influence on environment.
Display methods are main consideration in human-computer interaction and also need to be taken into account in display design. Aforementioned study (see Chiang et al., 2012, Chapter 2) states that display methods play important role in communication households with energy displays, and so better learning energy consumption information. They discuss consumer preferences in the design user interface and analyses three type of display methods: numerical, ambient and analogue, among which numerical display of energy consumption achieved best results in reduction of energy use. Other research (Egan, 1999) considers graph-based displays as one of the best communication ways to represent energy consumption data. During test several graph-based displays were examined which is most easily interact with consumers and motivate them to reduce energy usage. It is appeared that non-bell curved, distributional graphs are accurate and most preferred method of displaying energy use information.
Two temporal display factors: time duration to update measurements and type of time appearance (minute, hour, etc) are significant for interface design and need to be considered carefully. Periodicity of updating energy use on energy displays need to be at least as frequently as consumer looks at display and change energy use behavior. For instance, data of consuming energy for cooking appliances have to be updated in real-time or very near real-time, since these devices' usage is frequent and many energy conservation behaviors can be modified. But, periodicity for washing machine can be low, update for each washing, because during use of device just few energy saving decisions can be done. Type of time appearance also has varieties, which depend on other display design factors. Energy consumption data can be displayed in real-time or show consumption results of last energy consumption, last day/week, etc. But more essential type of monitoring information is combination of several types of time appearance, e.g. display real-time energy consumption and energy usage of current/last week/month simultaneously.

Rather than displaying energy consumption of each major appliance in home, it is more efficient group them according their location: bedroom appliances, kitchen appliances, etc., or functions: ‘wet’ appliances (dishwasher, washer machine), entertainment (TV, laptop, DVD). Displaying of grouped in such ways devices give households to view energy use activities more explicit and act towards energy savings (Wood and Newborough, 2007).

The other study (Anderson and White, 2009) examined the consumer preference on user interface design of energy displays. Participants tested energy displays with variable design interfaces during a week. Then they have been interviewed about the taken experience and were asked to draw ideal energy display interface. According to first group combination of current spending and overall spending of a day is the best visualization of energy consumption. They prefer to view monetary payment, than in kWh unit and pointed that using analogue feature - speedometer bar is also essential for user-friendly interface of energy display. Second group also prefer to view real-time consumption by speedometer, saying that “you can see where you are coming from and where you are going to”. However, other information (cost rate, historical spend, etc) they would like to see in numerical type. Also they state that they want to see the comparisons in rates of spending, e.g. rate of cumulative current daily spending with rate of past day spending. As for third group they favour having simple design, old-style scale with pointer to digital scale, they like to see a moving pointer to specific weight. Moreover, they prefer to view energy consumption rate in Watts, rather than other types and suggested to put lights, look like traffic light, to warn users about energy expenditure: green - low/normal energy use, yellow - medium, red - high energy use. Next group prioritized current rate of energy use in Watts with cumulative daily spend. They also include rate of CO2 emission and visual indicator in a case of high energy expenditure. The following group preferred numbers as digital method, than use graphics, they numerical method of displaying is more accurate. They also agreed to include rate of CO2 emission and put alarm bar, which change into red, when consumption increases.

According to discussed studies, design of energy displays is important for consumers to better interact with the measuring appliance. However, their preferences in user interface of energy displays have discordance of opinions, albeit several similarities in visualization of energy consumption they have.
Chapter 5 Design Methodology of Real-Time Energy Display

The most visible part of any measuring system (smart meter, IHD) is display interface, which provides householders with visualization of energy consumption data. It can aid the consumers to understand and modify their energy usage and attitudes, reducing bills and CO2 gas emissions. Therefore, user interface design of the energy display has to be considered carefully. According to aforementioned chapters’ analysis, design methodology of real-time energy display is created and described in this Chapter. It includes identification of the main stakeholders and key driver, definition of requirements and appropriate hardware selection.

In addition to this study research questionnaire regarding user preferences of in-home energy displays was created, and participated households were interviewed. Analyzed participants answers and discussion are presented in the first section of the Chapter (Section 5.1). This information is valuable for defining requirements and making initial sketches of the display design.

5.1 Questionnaire
Communication with potential customers is very useful, if not a necessary condition. Therefore, to discover what exact preferences of consumers considering aforementioned studies small questionnaire was prepared and distributed among random people to fill them. Questionnaire includes 13 questions regarding display methods, categories, display units and motivational factors (see Appendix B). Respondents were asked via both e-mails and face-to-face communication. The results of the questionnaire performed are below:

Overall 52 respondents were questioned, the participation of men and women were equal (50%/50%). They have been divided into five age-groups: up to 25 (12%), 26-35 (48%), 36-45 (8%), 46-55 (8%), 56 and over (25%) (see Figure 5.1). Most of them (44%) have full-time job, 19% - self-employers, 17% - pensioners, 13% of them are students, and others are unemployed and part-time employees (2% and 4% respectively). 27% of respondents say that they are totally positive towards energy savings, 25% of respondents are partially energy aware and occasionally take some actions on energy conservation, and 23% say that they are neutral towards energy savings and sometimes may behave to consume less energy. However, other respondents’ energy saving
attitude is more negative: 6% of interviewers are nonchalant about energy awareness, and other 17% say that saving energy is not a part of their current work day culture (see Figure 5.2).

![Figure 5.2 Percentage of energy awareness](image)

Their average energy expenditure in a month are quite high: 33% spend 101-200 kWh, 27% - 200 and higher kWh, but 12% of participants absolutely are not aware of their energy spendings (most of them were young people up to 25 and students). May be therefore, almost all of them (81%) would like to use IHD in their houses, but 55% (most of them were from group 46-55 and 56 and over, and pensioners) would use it in a purpose to save energy, and others just for interest. But neither of them are satisfied with their current energy metering system and feedback receiving methods (current billing system). Respondents emphasized monetary rewards (45%) and setting goals on energy saving (27%) as the most effective motivational factors for energy conservation. 65% of participants prefer to view energy consumption in monetary rate, and only 32% in kWh: it can be explained that households better understand energy consumption in monetary rate, than in kWh, thus can better influence on their energy conscious behavior.

![Figure 5.3 Percentage of display type preferences](image)

As for the design of energy display, more than a half of respondents prefer to use numerical display (67%), rather than analogue (21%) or ambient displays (12%) (see Figure 5.3). Elderly and adult people give their preferences to numerical and most young people prefer to use other two displays, saying that it can bring more interest to monitor energy consumption in house.
However, to a question “Should energy display be a colorful or black and white?” participants’ answers were controversial: 48% (mostly young people) prefer to have colorful displays and 42% (mostly adults and elderly people) say that they do not care of whether display is colorful or not. Respondent interest in receiving two types of awareness mostly: lights (46%) and popup messages (32%), in a case of energy consumption increases. Only 8 respondents (14%) chose sound signals. However, for 7% of respondents awareness signals are not necessary (see Figure 5.4).

![Figure 5.4 Percentage of preferences in awareness signals](image)

Also they point that displaying energy consumption measurements in cumulative energy consumption rate (34%) and separate energy consumption of each home appliance (39%) are the most effective ways to get valuable information about energy use. Respondents prefer receiving cumulative energy consumption of last week/month (57%) as additional information, current and last week comparisons can aid them to learn their energy consumption and keep it in one level. 19% of respondents prefer having tips about saving energy to receiving information about energy peak periods (11%) or monetary rates of peak periods (13%).

### 5.2 Stakeholders and Key Drivers

In this section the stakeholders and key drivers are described and discussed in details. The section starts with an introduction of main stakeholders and continues with their concerns. After that the drivers are derived and discussed.

To create user-friendly application it is important involve main users of the app into design process from the beginning. The design has to include intended purpose of the display, i.e. change user behaviour towards energy saving. Therefore, as main stakeholders only potential residential end-users of the energy display are considered. During investigations in Section 4.4, preferences of different age-group users on energy display design were variable. For this reason, to cover all consumers’ preferences, users are divided into three age-groups: elderly, adult and young.

- **Elderly end users** - potential residential consumers from the age-group 65 and over, mostly pensioners and people with minor disabilities, such as poor eyesight.
- **Adult end users** - around 36 and 64 potential end users, mostly of them have full-time jobs, little free time.
- **Youth end users** - potential end users of up to 35 age-group, mostly of them are students.

The stakeholders have different perspectives on the IHD, expectations and goals. In the following Table 5.1 stakeholders of the different groups will be clarified.
### Stakeholders' Concerns

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>Concerns</th>
</tr>
</thead>
</table>
| Elderly end users  | **Usability:** elderly should easily use IHD. The interface should be designed in such way that elderly with minor disabilities (poor eyesight), can use it.  
**Learnability:** elderly should learn how to work with device easily and fast to manage interact with it.  
**Comfortability:** elderly should feel comfortable in an environment surrounded by these energy display appliances: screen, sensors, etc.  
**Readability:** elderly should easily read and understand measuring characteristics displaying on the screen to act towards energy consumption.  
**Reliability:** elderly should rely on displayed measurements collecting via IHD.  
**Profitability:** elderly should achieve main purpose of the IHD: reduce energy consumption and save budget on billing. |
| Adult end users    | **Usability:** adults should easily use IHD, i.e. interaction with display should be short but frequent.  
**Reliability:** adults should rely on energy consumption information receiving from IHD.  
**Readability:** information on the display should easily readable by young users.  
**Profitability:** adult users should achieve main purpose of the IHD: reduce energy consumption and save budget on billing. |
| Youth end users    | **Usability:** young users should easily use the device.  
**Reliability:** young people should rely on their energy consumption information monitoring by IHD.  
**Profitability:** youths should receive profits from saving energy, which can be achieved by using the display.  
**Privacy:** energy consumption information should be secure and private.  
**Readability:** information on the display should easily readable by young users |

**Table 5.1 Stakeholders’ concerns**

After identifying the stakeholders and their concerns, an evaluation of the importance of those concerns in regards to the stakeholders’ importance is made in the Table 5.2.

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>Weight</th>
<th>Usability</th>
<th>Learnability</th>
<th>Reliability</th>
<th>Comfortability</th>
<th>Profitability</th>
<th>Privacy</th>
<th>Readability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elderly</td>
<td>0.33</td>
<td>25</td>
<td>15</td>
<td>15</td>
<td>10</td>
<td>20</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>Adult</td>
<td>0.33</td>
<td>25</td>
<td>15</td>
<td>20</td>
<td>-</td>
<td>25</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>Youth</td>
<td>0.33</td>
<td>15</td>
<td>-</td>
<td>25</td>
<td>-</td>
<td>25</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Overall*</td>
<td>1</td>
<td>21,5</td>
<td>10</td>
<td>20</td>
<td>3,3</td>
<td>23</td>
<td>6,6</td>
<td>14,9</td>
</tr>
</tbody>
</table>

**Table 5.2 Drivers related to stakeholders**
Evaluation of the most important concerns has been done according to the following equation:

\[ \text{Score} = E(\text{weight} \times \text{concern}) + A(\text{weight} \times \text{concern}) + Y(\text{weight} \times \text{concern}). \]

The drivers with the highest relative score were selected as key drivers. The three selected drivers directly influence on user interface of energy display, and explicitly explained below:

- **Usability** - is the main concern of all end users in using energy display and main driver in designing beneficial user interface. Usability contains, such design aspects as display types, display methods, size of characteristics, the colour contrast between characteristics and the background, etc. (explicitly discussed in the Section 4.4). All these factors can increase usability of the displays.

- **Reliability** - all information about customers’ energy usage need to be highly reliable, i.e. data has to be measured correctly and displayed in real-time or near real-time, so end users can behave immediately to save energy.

- **Readability** - is also key driver in designing interface for energy consumption display, because all users need to be able to accept and understand displaying data about their energy use and act to save energy in real-time. Ability of users to read clearly information can influence on energy use and money savings.

Despite on fact that profitability is considered and prioritized by all three groups of users, is not valuable as a key driver and does not include in main aspects for designing user interface of the energy display, but in general it is one of the main target and concern of all end users when they use the display, and it is a reason why profitability got high rate. Significant profitability cannot be achieved during short period of display usage; it needs a time to modify behavior. The study carried out for short period. Therefore, profitability is not considered as one of the key driver in this case.

Security and privacy are also not considered due to the main target of the study is to design efficient user interface for consumers, so main attention are given to design factors and aspects and their influence on user behavior.

### 5.3 Requirements

This section contains the list of requirements (functional and non-functional) for the IHD, which have been derived from literature review in the Section 4.4, questionnaire analysis in the Section 5.1. Each requirement in the following sections has a unique ID, a description, and a priority assigned to it. The prioritization is done by using the MoSCoW (Must, Should, Could, Would) (MoSCow method, 2013) method:

- **Must** perform requirements that must be satisfied in the final solution for the solution to be considered a success.
- **Should** is a high-priority requirement that should be included in the solution if it is possible. In most cases it is a critical requirement, which can be satisfied, if strictly necessary.
- **Could** represent a requirement, which is desirable, rather than necessary. It can be used when time and resources permit.
- **Would** describe requirements, which can be considered in the future by stakeholders, but not for current release.

#### 5.3.1 Functional Requirements

Functional requirements define capabilities and functions, which a system has realized successfully (Ofni Systems, 2013). These requirements comprise calculations, technical details, data...
manipulation and processing and other specific functionality which the system must meet (Func. req., 2013). As the work is for designing user interface of energy display, interface requirements mostly are determined and discussed here. Table 5.3 represents these functional requirements:

<table>
<thead>
<tr>
<th>ID</th>
<th>Requirements</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR01</td>
<td>The IHD shall allow end users to interact with the energy consumption measurement device at home using a special screen (PC, laptop, tablet, smartphone)</td>
<td>Must</td>
</tr>
<tr>
<td>FR02</td>
<td>The IHD shall provide end users with real-time (near real-time) feedback regarding household's energy consumption</td>
<td>Must</td>
</tr>
<tr>
<td>FR03</td>
<td>The IHD shall present the information on energy consumption in an easily understandable form.</td>
<td>Must</td>
</tr>
<tr>
<td>FR04</td>
<td>The IHD shall be able to monitor the energy consumption activity of each major appliance in the house</td>
<td>Must</td>
</tr>
<tr>
<td>FR06</td>
<td>The IHD shall be able to warn the users, when energy consumption increases</td>
<td>Should</td>
</tr>
<tr>
<td>FR07</td>
<td>The IHD shall allow users to view the data history of energy consumption in the house, so consumers can compare current and previous usage</td>
<td>Should</td>
</tr>
<tr>
<td>FR08</td>
<td>The usage information shall be displayed in monetary rate and kW or kWh and the display must include a visual (i.e. non-numerical) presentation that allows consumers to easily distinguish between high and low levels of current consumption</td>
<td>Must</td>
</tr>
<tr>
<td>FR09</td>
<td>The size of characteristics and contrast background with them shall be suitable for users who suffers from minor disabilities (e.g. poor eyesight)</td>
<td>Must</td>
</tr>
<tr>
<td>FR10</td>
<td>The IHD shall provide a motivational factors to reduce energy usage at home</td>
<td>Must</td>
</tr>
<tr>
<td>FR11</td>
<td>The IHD shall update energy consumption data each 10 sec</td>
<td>Must</td>
</tr>
<tr>
<td>FR12</td>
<td>The IHD shall to provide user with comparative energy use of each major appliance to encourage for energy saving</td>
<td>Should</td>
</tr>
<tr>
<td>FR13</td>
<td>The IHD shall backup relevant energy consumption data to the backup server</td>
<td>Would</td>
</tr>
<tr>
<td>FR14</td>
<td>The information about carbon dioxide gas emission or other environmental factors shall be provided by IHD</td>
<td>Would</td>
</tr>
</tbody>
</table>

Table 5.3 Functional requirements
5.3.2 Non-Functional Requirements

Non-functional requirements are requirements, which designate characteristics that can be used to judge system operation, then separate behavior (Non-func. req., 2013). Two types of non-functional requirements were considered: commercial and technical, which listed in the Table 5.4 and Table 5.5 respectively:

<table>
<thead>
<tr>
<th>ID</th>
<th>Requirements</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR01</td>
<td>The IHD shall reduce household's energy consumption for at least 10% in order to become an attractive product</td>
<td>Must</td>
</tr>
<tr>
<td>CR02</td>
<td>Different buying plans shall be provided to customers. This will allow users to include or exclude features of the IHD</td>
<td>Could</td>
</tr>
<tr>
<td>CR03</td>
<td>The time required for the customers to learn how to interact with the IHD shall not exceed six hours</td>
<td>Must</td>
</tr>
</tbody>
</table>

Table 5.4 Commercial requirements

<table>
<thead>
<tr>
<th>ID</th>
<th>Requirements</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR01</td>
<td>Users shall be able to install IHD in home by themselves and easy</td>
<td>Must</td>
</tr>
<tr>
<td>TR02</td>
<td>The installation of the IHD shall not exceed a day</td>
<td>Must</td>
</tr>
<tr>
<td>TR03</td>
<td>The IHD shall be able to interact with multiple appliances in home simultaneously</td>
<td>Must</td>
</tr>
<tr>
<td>TR04</td>
<td>The IHD shall support one of the following communication methods for hardware devices: Zigbee, USB, Bluetooth, WiFi or GSM/GPRS</td>
<td>Must</td>
</tr>
<tr>
<td>TR05</td>
<td>The IHD shall be connected to Internet, to share and compare preferred information with other consumers</td>
<td>Could</td>
</tr>
<tr>
<td>TR06</td>
<td>The IHD shall interact with other hardware (e.g. transmitter, sensor clamp, circle) 24/7</td>
<td>Must</td>
</tr>
<tr>
<td>TR07</td>
<td>Consumer shall use the IHD easily</td>
<td>Must</td>
</tr>
<tr>
<td>TR08</td>
<td>The IHD shall be scalable to add new features/ appliances easily</td>
<td>Should</td>
</tr>
</tbody>
</table>

Table 5.5 Technical requirements
5.4 Use Cases

In the following section use cases are listed and described. The use case diagram, which presents the most important use cases of the system, is illustrated below in Figure 5.5.

Concerning main stakeholders that described above the 3 most important use cases were identified: view real-time energy consumption, view energy consumption of home appliances and view historical data of energy use. These 3 use cases are shown below, and were used in analysis for the requirements of the application.

**UC-01: View real-time energy consumption**

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>IHD users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Collected by Power Meter Clamp real-time energy consumption data of the whole home is viewed by user on main page of the app.</td>
</tr>
<tr>
<td>Requirements</td>
<td>FR-02, FR-03, FR-06, FR-08, FR-09, FR-11, TR-04, TR-06</td>
</tr>
</tbody>
</table>

**UC-02: View energy consumption of home appliances**

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>IHD users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Real-time energy consumption data of each home appliance is viewed by user when he/she goes “Appliances Expenditure” page in the app.</td>
</tr>
<tr>
<td>Requirements</td>
<td>FR-02-FR-04, FR-09, FR-11, FR-12, TR-03, TR-04, TR-06</td>
</tr>
</tbody>
</table>
5.5 Hardware Components
According to above mentioned investigations of IHD and questionnaire about display user interface (Chapter 4) following types of hardware components can be included in in-home energy display (IHD) system to perform comfortable usage of the energy display:

- *Display unit* is one of the main parts of IHD hardware that is used to visualize information about collected in real-time measurements and calculated rates of domestic energy consumption (e.g. monetary rate, kWh rate, CO2 emission rate). As it was discussed above in Section 4.4, most participated householders prefer to have portable display, which can be easily transferred around house and also can be easily hung on a wall. For this reason using tablets as a monitoring tool can perfectly satisfy end-users’ preferences.

In this study Android-based tablet computer produced by Samsung is used for providing energy use information to consumers (types of the Samsung tablets are shown in Figure 5.6). Special application for measuring energy usage will be installed and during experimental session consumers will be able to monitor their energy use.

Figure 5.6 Types of Samsung tablets
• **Sensor clamps (clips)** are important part of the most IHD in a current market, they enable customers to measure electricity consumption of entire house. They stick to power cables connected to electricity meter and monitor magnetic field around them to measure the electrical current passing through cables.

![Aeon Labs Power Meter Clamp](Picture is taken from Vesternet, 2013)

One of such devices is Aeon Labs Power Meter Clamp (see Figure 5.7) easy to install in main electricity box: clamps are clipped around the incoming electricity cables and no needs for electrical or wiring changes (Vesternet, 2013).

• **Sensor plug socket** is an energy measurement device that should be putted between a socket and an appliance plug to measure consuming electricity of the connected appliance.

Plugwise circle (see Figure 5.8) stores and transmits data of electricity usage to the software installed on the display unit, using a wireless ZigBee-mesh network. Moreover, connected appliance can be switched on or off by using the Circle. It is equipped with a standby killer: connected to the Circle appliance in standby mode, can be totally interrupted from power to prevent unwanted energy usage (Plugwise, 2013).

![Plugwise circles](Picture is taken from Plugwise components, 2013)

• **Transmitter** is a type of IHD hardware, which collects electricity consuming data from sensor clamp and/or sensor plug sockets. These types of transmitters can be used in one IHD system, collecting energy use of whole home and/or connected to sensor plugs home.
appliances and sending these data to display unit. Following described types of transmitters can be used in this study:

![Figure 5.9 Plugwise stick (Picture is taken from Plugwise, 2013)](image)

First is the Plugwise Stick (see Figure 5.9) communicates with the wireless sensor plugs within the network. The Stick provides software with collected power consumption data and transmits tasks to the installed Plugwise modules. This is done through a wireless ZigBee-mesh network. The Stick connects to a display unit via USB port (Plugwise, 2013).

Other type of transmitter collects data from sensor clamps and transfers it wirelessly to visual display unit (see Figure 5.7). Mostly they attached to sensor clamp through cable and placed into electricity box.

For better visualization of all hardware connections schematic hardware overview is presented below in the Figure 5.10:

![Figure 5.10 Schematic hardware overview of the whole IHD](image)

### 5.6 User Interface Design

User interface (UI) is a space where human-machine interaction happens, i.e. where user controls software application or hardware device. The goal of any UI is to be a user-friendly, which allows user communicate with software or hardware in intuitive and natural way. The interface can be designed for software or hardware, or for combination of both (User interface, 2009).

The main aim of the design of the energy display interface is keeping visualization of energy use pretty simple by using simple graphs and digitials. According to Chiang et al. (2012) and Egan
(1999) (Section 4.4) numerical and graph-based displays are most effective ways to represent energy use data. In UI design both of these types are used. Contrast between background and text is necessary for the user to be able to distinguish text. UI with insufficient contrast can be tiring, even impossible for people to read. Therefore, it is decided to enhance contrast between background and use black background and white text, which increase readability is one of the key driver (see Section 5.2).

The UI consists of three pages: (1) Main page, (2) Appliances expenditure and (3) Expenditure history.

1. **Main page** shows overall energy consumption of a house (see Appendix C, Figure a). During discussion on questionnaire section (Section 5.1) most of participants preferred to know their overall energy use, and have each home device energy expenditure as an additional information. Therefore, measurement data from electricity meter is displayed in the main page. Current rate of energy consumption is presented in graphical (three-colored bar chart) and in numerical methods (three types of digital rates). Participants of aforementioned study (Anderson and White, 2009) discuss effectiveness of traffic lights, three-colored bar chart imitates this traffic lights, which would change color (from blue through red) as current rate of expenditure increased, thereby alert households about increase in their energy use. Numerical rates show current energy consumption and comparison between current and last day cost expenditures.

2. **Appliances expenditure** shows list of connected to the IHD home appliances and their energy expenditures in numerical way (see Appendix C, Figure b). There can be seen each devices real-time consumption and comparison between current week and last week energy usage.

3. In **Expenditure history** page user can find historical data regarding overall energy expenditure of last month (see Appendix C, Figure c). Moreover, comparison between current month and last month consumptions is also presented here and graphical visualization of each day energy consumption of last month. It aids households to better understand their energy consumption and change attitude towards energy conservation.

Additional for UI design special logo for the application is made, which is shown in the figure below (see Figure 5.11):

![Figure 5.11 Application logo](image-url)
Chapter 6 Implementation

The implementation comprises all the processes that engaged in developing new software or hardware, which exploits in its environment. This environment includes the installation, configuration, running, testing and so on (SearchCRM, 2007).

In this Chapter the implementation of the IHD software is presented, it includes the information about system and software architectures of the IHD.

6.1 System Architecture

System architecture represents mapping of the software architecture into the hardware architecture, and human interaction with these components (PBWorks, 2006). In this section description of the initial model of the IHD is described in details. It depicts hardware and software components relationships, and user interaction with them.

![Figure 6.1 Initial Model](image)

Initial model of the IHD is presented in the Figure 6.1, which consists of the following main components:

- **Measuring devices** are hardware part of the IHD that includes special equipments: Plugwise stick, Plugwise circle+ (more detailed explanation about these devices is presented in the Section 5.5) that are used to measure, collect and send electricity consumption data. Measuring devices uses ZigBee network to communicate and transmit data between each other.

- **xPL - Perl API** is the part of the software component that aids to get electricity consumption data from measuring devices and to control it.

- **Base Station** receives every 3 sec. electricity measurement data from xPL-Perl API, and sends to the Web Service each 3 sec. Before sending data to the Web Service it performs calculation of the data.

- **Web Service** is used here as a bridge to connect Base Station and Android app. Google App Engine (GAE) is used in IHD software as the type of Web Service. GAE is a cloud-computing platform for developing and hosting web-applications in Google infrastructure. GAE can handle multiple datacenter outages without any downtime, which is very important in real-time and continuous data transfer (GAE, 2013).
• Android App provides to the end-users measurement data that comes from Web Service (More information is represented in the Section 6.2.1).
• End user interacts with IHD through Android App that installed in the display, monitors and controls his/her energy consumption.

6.2 Software Architecture
Software architecture of an application is the process, which defines structured solutions for optimizing quality attributes (non-functional requirements), as manageability and performance and for satisfying requirements, as operational and technical. It comprises set of decisions that based on different factors and can influence on maintainability, performance, quality of the app (MSDN, 2013).

In this section software of the IHD is represented in details. Software design decisions are explained in the first section followed by architectural view model.

6.2.1 Software Design Decisions
In this section the software related decisions that have been made about the technology used to build the system are introduced.

Before building the energy measuring application development environment and programming language were considered and it is decided to build the application for Android platform. There were few reasons why Android has been chosen. Firstly, a wide variety of Android devices with different designs and specifications for any budget allows customers choose what they want (MIUI, 2013). As for developers, Android innovation enables build powerful and different type of applications that use up-to-date technology (Developer, 2013). Android OS is an open-source platform that based on the Linux kernel and multiple open-source libraries and provides multi-platform support. It gives to developers the freedom to contribute to or to extend the platform and make developments on Windows, Mac OS or Linux (Grell, 2010). Therefore, the following softwares are chosen to build the application for energy display:

• Android SDK is a software development kit that provides API libraries and developer tools necessary to build, test and debug application for Android platform. It comprises sample projects with source code, development tools, debugger, an emulator and required libraries to create Android app (Webopedia, 2013).
• Eclipse IDE is a complex, multi-language and extensible Integrated Development Environment for Java projects (Grell, 2010)). It aids not only build Java programs, but allows to develop Android-oriented code and test it on emulator that shows how created code would run in standardized version of chosen Android device (Williams, 2012).

6.2.3 Architectural View Model
In order to describe the software architecture of the IHD the 4+1 Architectural View Model (Kruchten, 1995) is used. In general, the model comprises of the following views: use cases view, logical view, process view, physical view and development view. Not all views are documented, just most important: logical view, process view and in addition data view.

• Logical view
Logical view shows the overview of the IHD in terms of structural elements and mechanisms.
Software architecture of the IHD system consists of the following layers (see Figure 6.2):

*Presentation Layer* (User Interface): Responsible for presenting information to the user and interpreting user commands. It is an access point for end-users to connect to the IHD.

*Infrastructure Layer*: Processes commands and handle data communication between Presentation Layer and Web Service.

*Web Service*: Provides Presentation Layer with the data. More information about Web Service can be found in the Section 6.1.

![Figure 6.2 Architectural layers](image)

**Data view**

To be able to transfer the measured electricity data among Base Station, Web Service and Android App the data object is converted to JSON\(^1\), (JavaScript Orientation Notation) lightweight data-interchange format. Data objects that received by Base Station are converted here to JSON based on the standard format and sends to the Web Server. Android App pulls JSON file to Web Service and receives JSON with data.

Schematic overview of the main data transfer in the IHD software is depicted in the Figure 6.3.

![Figure 6.3 Data transfer](image)

IHD has no special database to store all measurement data coming from Measuring devices, However, Base Station has text file that every 5 min store data in it, and it can be used as backup data storage.

\(^1\) [http://www.json.org/](http://www.json.org/)
• Process view
  Process view is represented with activity diagrams describing how processes are running. The description of processes was captured in divided parts of activity diagram. Represent just one single activity diagram would not be well readable and clear due to size of it, that is why diagram is represented in few diagrams. These two diagrams illustrate detailed data process of the IHD that starts from Measuring Devices to Android App.

AD-01: Data flow from Measuring Devices to the Web Service

| Description | This activity diagram models part of the data path that starts from measuring devices and goes to Web Service through Base Station |
| Trigger | To collect measurement data from Measuring Devices (Plugwise Circle+ and Plugwise Stick) and to send it to Web Service |

![Activity diagram: data flow from Measurement Devices to the Web Service](image)

Figure 6.4 Activity diagram: data flow from Measurement Devices to the Web Service

AD-02: Data flow from Web Service to Android App

| Description | Android App pulls measurement data from Web Service that received it from the Base Station |
| Trigger | To show measurement data on the Android App |
Figure 6.5 Activity diagram: Data flow from Web Service to Android App
Chapter 7 Evaluation

Program evaluation is the detailed assessment of the program or project outcome to determine whether established measures or expected results were achieved or not (Business Dictionary, 2013). It includes systematic methods for collecting and analyzing information about the program or project, which particularly focus on its effectiveness and efficacy. During evaluation the following assessment stages should be considered: (1) importance of the program, (2) design and logic/theory of the program, (3) implementation of the program, (4) program’s outcome and impact and (5) efficacy of the program (Prog. eval., 2013).

To answer on the main thesis question that has been mentioned at the beginning of the research (see Section 1.1): “Can the real-time displaying of energy usage information affect the behavior of household end-users with respect to their energy consumption?” evaluation of the built in-home energy display (IHD) is conducted and described in details here. The evaluation consists of the following main assessment stages: experimental setup, experimental sessions and results. After evaluation of these results the answer on the main question can be done.

7.1 Experimental Setup

Growth in number of electronic devices in each home and the way in which these technologies become part of the everyday life influence dramatically on increase of households energy consumption (Crosbie, 2008). For instance, the average number of home appliances of each UK household is around 41 (compared to 1970’s home had about 10 electrical devices) (Owen, 2012), majority of which account for entertainment appliances. According to the Energy Saving Trust by 2020 entertainment devices (incl. gadgets, computers, etc.) will consume 45% of total energy of residential sector (Owen, 2007). Few studies (Crosbie, 2008, Owen, 2012) that researched households electricity-using habits state that the most popular and commonly-used entertainment equipment is TV. For instance, the UK households have on average 2.5 television and each the US family has 2.8 TV at home. Moreover, every household spends approximately 6 hours in a day watching TV. Television became one of the stylish household accessories and replacement of other devices, such as electronic picture frame or digital radio (Crosbie, 2008).

The energy consumption of TV depends on type and size of the TV, e.g. annual consumption of the following three types of TV: CRT-traditional - 118 kWt, LCD-flat screen - 199 kWt, Plasma-flat screen - 658 kWt (Owen, 2012). Therefore, to reduce the energy consumption households need to make usage of mostly-used home appliances, as TV, more efficient and modify their energy conscious behavior during their use. Standby mode of the electricity devices found as one of the reasons of increasing electricity use. It is analyzed that if every UK household avoids using standby mode, saved electricity would be enough to power 2,7 million houses for a year (Crosbie, 2008). Majority of the interviewed households in the study (Crosbie, 2008) state that they habitually leave their TV on standby. Others have habits to use TV as a computer monitor, electronic picture frame, digital radio or music system. Television consumes electricity up to 250 W/h when in use, while digital radio consumes about 8.5 W/h, music system uses 6.1-44W/h, it follows that using TV instead of digital radio or music system costs for household much more money for energy bill (Crosbie, 2008).
The main aim of the experiment is to find out whether participants change his/her attitude of using home appliance or not in case of receiving frequent feedback of energy consumption via the IHD. We analyse participating households’ behaviour towards effective use of electrical equipment by giving them real-time energy consumption feedback and information about efficient use of energy. Due to frequent use of television by the most of households, TV has been chosen as examination home device. During experimental period participants monitor electricity consumption of TV through the IHD. Experiment also includes evaluation of usability and effectiveness of the IHD interface: how participants can interact with display, understand and accept information on it, and most important use the data and act according to it.

According to investigated studies that are listed in the table in Appendix A, combination of real-time feedback, information and goal settings bring better results in reduction of energy consumption. Therefore, in order to achieve significant results in the experiment these combination of the behavior modification strategies are used. Household receives real-time feedback through IHD device, goal settings and information regarding efficient use of home appliances are presented at the beginning of the experiment. The goal setting is assumed rate of electricity use by TV of each participated home, which household should not exceed when use TV. More details about the goal setting are described in Section 7.2.2.

7.2 Experimental Sessions
Duration of experiment for each household is a week, during which they monitor electricity consumption of their TV through IHD installed in their homes. Detailed information about IHD installation and hardware components can be found in the Section 7.2.3. Moreover, participants receive additional information, such as tips on effective use of TV (e.g. do not leave TV on standby mode).

Entire experimental session is divided into 5 stages: selection of participants, introduction of study, IHD installation, measuring and examination of behavior change, which are described in the following sections.

7.2.1 Selection of Participants
Two households (household A and household B) participate in experimental sessions. They are selected according to their differences in attitude towards use of television and in time contribution of TV. It gives opportunity to investigate participants’ behavior and gives variable measurement data, which aids to analyse electricity consumption of TV and to make comparison between them.

Household A has 2 members: mother (unemployed) and son (student). She runs the house and most of her time spends at home watching TV, therefore the time of using TV is the longest (6 hours), comparing to other participating household. In household B only one person, he has full-time job, and sometimes works in weekends also. So, he spends less time watching TV, in general it is evening time after work for 2.5-3 hours before going to bed.

Average electricity consumption data and detailed characteristics of the households are represented in the Table 7.1. It also includes information about households TV (type, size, energy efficiency level (EEL), etc.), average time of TV use in a week, amount of time that is used in one kWh, etc.
<table>
<thead>
<tr>
<th>Features</th>
<th>Household A</th>
<th>Household B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of members, age, employment</td>
<td>2 persons: housewife (50 years old), student (29 years old)</td>
<td>1 person: full-time employee (35 year old)</td>
</tr>
<tr>
<td>Average electricity consumption for a month</td>
<td>70-75 kWh</td>
<td>25-30 kWh</td>
</tr>
<tr>
<td>Amount of TV, type, size, EEL/Energy Star</td>
<td>1 LCD TV (LG), screen 81 cm diagonal, Energy Star</td>
<td>1 LCD TV (Samsung), screen 80 cm diagonal (32 inch), EEL is B</td>
</tr>
<tr>
<td>$V^2$ (hours of TV use in 1 kWh)</td>
<td>5 hours</td>
<td>5 hours</td>
</tr>
<tr>
<td>$H^3$ (average time of use per week)</td>
<td>42 hours (6 hours in a day)</td>
<td>21 hours (2.5-3 hours in a day)</td>
</tr>
<tr>
<td>$W^*$ (kWh of use in a week)</td>
<td>8.4 kWh</td>
<td>4.2 kWh</td>
</tr>
</tbody>
</table>

Table 7.1 Households characteristics

* $W$ is assumed amount of electricity consumption by TV that has been calculated according to the following formula: $W = \frac{1}{V} \times \frac{H}{V}$, here $V$ is 7 hours of Standard TV use or 5 hours of LCD TV use or 3 hour use of Plasma TV in a 1 kWh. $H$ and $W$ are expected rates of time and kWh, respectively that participants should use during the experiment period.

7.2.2 Introduction of Study
At the beginning of the experiment every participant is introduced with the study rules and how to use the IHD, control data measurements and how to act regarding that information. In addition, households are interviewed individually about their knowledge in energy consumption. It has emerged that household A is aware of effective energy consumption, and have some energy conscious behaviour, e.g. they turn off the light when leave room, use daylights instead of artificial when it possible. But leave TV in standby mode and use it as background noise. Household A is interested in reducing energy consumption and cost of electricity bill. As for Household B is also aware of the efficient energy consumption, but does not use it in life.

To increase the households knowledge in energy saving few tips for making use of TV more effectively have been prepared and have been suggested to follow them during the experiment period. There are:
- Do not leave your TV in standby mode;
- Switch TV off when you leave home, or for a night and when not using it;
- Do not use TV as a background noise;
- Check energy efficiency label (EEL) before buying new TV;

---


3 Does not include standby mode time
Do not use TV as replacement for other entertainment equipments, as electrical frame, digital radio, alarm, etc.

There is given detailed explanation of how participant uses IHD during experiment: the IHD tablet is placed next to TV that gives household to monitor energy consumption of TV during watching it. It is expected that the frequent and daily monitoring of energy consumption can help participant to control his/her expenditure. Household interacts with the display through Appliances Expenditure page of the built Android app, where measurement information, such as real-time electricity use of TV, and rates of TV expenditure of a current week and a last week, are presented. Due to time restriction of the experiment (a week for each household), the last week rate is empty. Household receives rates of real-time consumption and current week. Current week rate is the electricity measurement that was consumed during the experimental week. So there is no comparison between current week and last week. Instead of that households have been given goal setting, according which their electricity usage of TV in a week should not exceed goal setting rate. The goal setting rate (W) is assumed measurement rate of used electricity of the household TV for a week, it is calculated by using average hours of watching TV in a week, hours of TV use in 1 kWh (U, V, correspondingly, see Table 7.1). More detailed calculation is presented in the Section 7.2.1. We assume that this derived rate (W, see Table 7.1) is household’s average electricity expenditure of TV in a week, and at the end of the experiment this rate is compared with measurement data of the current week. Measurement data of the current week is presented in the Section 7.2.4.

7.2.3 IHD Installation

After the study introduction IHD was installed in participants’ houses. In experiment only one IHD was used, due to expense of hardware components. Therefore, IHD was installed in sequential order: first, in household A, then in household B.

The IHD that is used for experiment comprises of the following parts:

- **Tablet**: Samsung Galaxy Note 10.1 tablet (1280x800), for visualizing energy consumption data.
- **Measurement devices**: Plugwise Home Start Kit includes Circle+ and Stick (more information can be found in Section 5.5), for measuring and collecting energy consumption data.
- **Software**: Components are energy monitoring application built for Android, Web Service and Base Station, for being able to connect hardware components, handle data, and display it on the screen.
- **Laptop**: Here laptop plays role of the bridge between Plugwise Stick and Tablet (Base Station), it collects data from the stick and sends it to the tablet.

Figure 7.1 Hardware connection overview
Overall hardware connection of the pilot IHD is depicted in the picture above (Figure 7.1): An important aspect that has been considered during the experiment is location of the display (Anderson and White, 2009). It aids users to get the most out of their display and encourage them to look at it. The most convenient location for display that shows energy consumption of the TV is next to TV. Therefore, the display is placed next to TV in all participating homes.

### 7.2.4 Measuring

Measuring session includes 2 weeks of using IHD (each week for every household), during which energy use data was measured and collected. Participants were asked to fill the table below (Table 7.2): they wrote down every day measurement of electricity consumption of TV (it includes consumption during using TV, plus standby mode) and time duration of watching TV. The measurement has been taken from current week rate at the end of the each day during experimental week.

<table>
<thead>
<tr>
<th>Energy consumption</th>
<th>Household A</th>
<th>Household B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current week rate</td>
<td>Everyday consumption</td>
</tr>
<tr>
<td>1st day</td>
<td>0.48 kWh</td>
<td>0.48 kWh (around 6 hours)</td>
</tr>
<tr>
<td>2nd day</td>
<td>1.25 kWh</td>
<td>0.44 kWh (around 5 hours)</td>
</tr>
<tr>
<td>3rd day</td>
<td>1.80 kWh</td>
<td>0.55 kWh (around 7 and a half hours)</td>
</tr>
<tr>
<td>4th day</td>
<td>2.59 kWh</td>
<td>0.79 kWh (around 10 and a half hours)</td>
</tr>
<tr>
<td>5th day</td>
<td>3.30 kWh</td>
<td>0.71 kWh (around 9 and a half hours)</td>
</tr>
<tr>
<td>6th day</td>
<td>3.95 kWh</td>
<td>0.65 kWh (around 8 hours)</td>
</tr>
<tr>
<td>7th day</td>
<td>4.38 kWh</td>
<td>0.43 kWh (around 5 hours)</td>
</tr>
<tr>
<td>Overall</td>
<td>4.4 kWh (51 and a half hours in a week)</td>
<td>1.2 kWh (20 hours in a week)</td>
</tr>
</tbody>
</table>

Table 7.2 Measurement data

As can be seen in the Table 7.2 both households (A and B) consumed much less electricity than expected. Household A used 4.4 kWh in a week, it is twice less than assumed rate 8.4 kWh (W, Table 7.1), albeit time period of TV use was longer for almost 10 hours than expected time (42 hours/week). While Household B watched TV as expected approximately 20 hours in a week
(expected 21 hours/week), but consumed electricity is 3.5 less than assumed (1.2 kWh than 4.2 kWh in a week). Current electricity consumption of both households televisions were different: TV of the household A used 80 W, while other TV used only 50 W, even both TV are LCD and have same screen size (32 inch). Both households behavior regarding to use of TV during experimental period is described in the Section 7.2.5.

### 7.2.5 Examination of Behavior Change

After a week usage of IHD each household has been interviewed about their experience in IHD use and monitoring electricity consumption, also their opinion and suggestions regarding to experiment, usability of the IHD and interface design were recorded.

- **Housewife from Household A** explains increase of the time of TV use during experimental week with summer vacation time that had students, during which her student-sun spent more time at home watching TV. During experimental week Household A followed tips that have been given at the beginning of the experiment. They tried to avoid standby mode and turned TV off when they do not use it, for night and when they leave house, also stopped use TV as background noise. However, there were few times when they forgot to turn TV off and left standby mode. It can be explained by the following: to adopt any new habit or change it a week is not enough time. Frequency of monitoring electricity consumption on the display was high at the first part of the experimental period, due to fear of exceeding goal setting rate (W). Second part of the experimental week they spend less time monitoring measurements, because they consumed twice less electricity and they were sure that do not exceed goal setting rate.

- **During whole period of experiment Household B** behaved himself as usual: watched TV very little, did not use it as replacement to other appliance (e.g. digital radio, digital frame, etc.), and left his television in standby mode, when did not use it. He did not change his behavior towards efficient use of home appliance. The participant explains it by little rewards: he does not want to change his daily habits for saving only few euros on electricity bill.

- **The interface design of the IHD application satisfied all participants.** Housewife from Household A admitted that she is not good with gadgets and still has difficulties with using them; therefore, she appreciated simplicity and usability of the IHD application. She learned how to use it very fast and during usage of the display was able to monitor and understand displayed data herself. Her sun is dim-sighted, and thus estimated highly large numerical indicators of electricity consumption. As for Household B does not pay much attention to interface design, prefers instead having more features. He suggested adding ‘turn appliance on/off’ feature to the app, to be able to control switching on/off appliance in a distance from plugs. This can aid to avoid standby mode of home device.
Chapter 8 Conclusion, Discussion and Further Work

The main focus of the researched thesis work is to investigate the influence of real-time displaying of energy use information on the households energy conscious behavior, which can aid them in energy saving. As was mentioned above, the most effective way to send real-time energy consumption feedback is to use in-home energy displays. Different types of IHD are available in the current market, however, not all satisfy users’ requirements in usability and help to achieve significant results in reduction of energy consumption. In the thesis work more effective for households IHD with information that motivates to change attitudes towards energy consumption is designed and evaluated.

The thesis study consists of the following three main stages:

1. In the first stage information that relates to effective energy consumption is analyzed. Number of studies are reviewed and researched to understand what knowledge is valuable in reduction of domestic energy use and what information can motivate households to save energy and need to be included into feedback that households receive through IHD. There are number of factors that have direct or indirect impact on energy-related behavior, such as home characteristics (number of rooms, home insulation, window glazing, etc.), energy-related attitudes (energy knowledge, responsibility, etc.) and household lifestyle (social-cultural factors, personality values, etc.). In order to modify energy conscious behavior household needs to be aware of these factors and to manage them. This information aids household save energy use.

2. In the second stage design of the IHD interface and developing of whole software for measuring electricity consumption are described. For designing user-friendly interface 52 people of different age were interviewed about their preferences in energy display. For this purpose questionnaire that includes questions about design characteristics and features is prepared. It is revealed that more than a half of respondents prefer to use numerical display (67%), rather than analogue (21%) or ambient displays (12%). 65% of participants prefer to view energy consumption in monetary rate, and only 32% in kWh: it can be explained that households better understand energy consumption in monetary rate, than in kWh, thus can better influence on their energy conscious behavior. Results of this interview aids to identify main requirements that have to be considered in design of energy display interface. Also attention is paid on the results of studies that analyzed efficiency of the current energy displays. And according to the combination of these results the interface of the IHD is built. It includes a combination of graphical and numerical views, motivational factors, real-time feedback and historical data.

3. The third stage includes the description of evaluation of the IHD. Entire experimental session is divided into 5 stages: selection of participants, introduction of study, IHD installation, measuring and examination of behavior change. Duration of experiment for each household is a week, during which they monitor electricity consumption of their TV through IHD installed in their homes. Television is one of the common-used entertainment device, which consume significant domestic electricity. And by changing TV using behavior households can achieve reduction in electricity consumption. For that purpose participants receive real-time feedback via IHD and tips on effective use of TV (e.g. do not leave TV on
standby mode). The result of the two-week experiment in participated houses shows that combination of real-time feedback, information and goal setting have influence on households' behavior. Household A modified their attitude towards effective use of home appliances and adopted some energy efficient habits. As for the second household, his behavior remained unchanged due to little rewards that he can save on electricity by changing his daily habits.

Unfortunately, due to time restriction the experimental session of the IHD for participated households was not enough to completely change their behavior and use it as a daily habit. To get the significant reduction in energy consumption household needs to modify all behavior towards effective energy use, which consume much more time than a week. Therefore, in a future work experiment part will be prolonged for at least few months.

Moreover, for future work implementing some new features to IHD can be considered. One of them is switching on/off appliance, which will be implemented individually for each home device, listed on the Appliances Expenditure page. Households will be able to turn off any home device from display, it will avoid devices standby mode and thus, reduce appliances energy consumption.
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## Appendix A: Summary Table

<table>
<thead>
<tr>
<th>Study (author(s), year)</th>
<th>Behavior modification strategy</th>
<th>Interaction tool (SM, IHD, bill, etc.)</th>
<th>Expected results, target</th>
<th>Energy type</th>
<th>Experiment duration and number of participants</th>
<th>Findings</th>
<th>Achieved results</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. Costanza</td>
<td>Real-time feedback, monetary reward</td>
<td>SM</td>
<td>Design of energy displays allow users to understand their consumption data, and changes in their behavior</td>
<td>electricity</td>
<td>12 participants, 2 weeks</td>
<td>The design was largely successful in engaging users, but SM is not very useful to those who either consume very little or are already very aware of their energy consumption.</td>
<td>5 participants saved between 5% and 32%, 7 consumed more, from 3% to two peaks of 80% and 75% increases.</td>
</tr>
<tr>
<td>D. Allen</td>
<td>Real-time and continuous feedback</td>
<td>IHD</td>
<td>Explore the effect of real-time feedback in a residential setting</td>
<td>electricity</td>
<td>10 households, three months</td>
<td>IHD have a greater effect on energy consciousness than on conservation behavior in both high- and low-incomes homes.</td>
<td>Electricity use reduction values are 23.9 and 24 for subsample and total control group</td>
</tr>
<tr>
<td>S. Houde et al.</td>
<td>Real-time feedback</td>
<td>IHD</td>
<td>Assess the impact of real-time electricity consumption feedback to households</td>
<td>electricity</td>
<td>2 months</td>
<td>Morning and evening intervals show larger electricity reductions</td>
<td>Reductions in electricity consumption an average of 5.7 %</td>
</tr>
<tr>
<td>T. Hargreaves, 2010</td>
<td>Real-time feedback, motivation factors, information</td>
<td>IHDs</td>
<td>Focuses on motivations that change behaviour during IHD use</td>
<td>electricity</td>
<td>275 households, 1 month – 12 months</td>
<td>The IHDs with financial, environmental motivations have positive effect on energy saving. But</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Methodology</td>
<td>Technology</td>
<td>Context</td>
<td>Design Principles</td>
<td>Results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------</td>
<td>------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Perspective report, 2008</td>
<td>Real-time feedback</td>
<td>SM</td>
<td>Establish both qualitative and quantitative data on householders' reactions and use of the SM</td>
<td>Establish both qualitative and quantitative data on householders' reactions and use of the SM</td>
<td>Households read SM twice often, if display located in most accessible place. Much better results could be achieved with a more user-friendly SM, simpler instructions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W. Anderson et al., 2009</td>
<td>Real-time feedback, design principles</td>
<td>IHDs</td>
<td>Development of a core specification for IHD and their functionality</td>
<td>Key design principles of IHD: changing rate is better expressed as an analogue indicator, keep design simple, money rate is better understandable, etc.</td>
<td>33% of participants have lower fuel bill, 33% have higher bills. 50% is very likely to recommend SM to friends, and 19% quite likely.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L. McCalley, C. Midden, 2002</td>
<td>Real-time energy feedback, goal-settings</td>
<td>Washing machine control panel</td>
<td>Increase energy conservation behavior by giving consumers immediate energy feedback</td>
<td>Electricity 20 participants Pro-self individuals save more energy when allowed to self-set a goal and pro-social individuals save more energy when assigned a goal</td>
<td>Self-set and assigned groups, reduced their energy use by 21.9% and 19.5%, respectively</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. Ueno et al., 2005</td>
<td>Energy consumption information feedback, energy-saving activities</td>
<td>IHD</td>
<td>Focused on the awareness of residents to energy conservation and on the potential</td>
<td>Electricity 9 households, 2 months Participants became interested in the daily-load curve, power consumption of many appliances had been reduced</td>
<td>9% of average reduction in power consumption. 5% of the power consumption of</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
of reducing energy demand through energy-saving activities

| G. Wood, M. Newborough, 2003 | Electronic feedback, information | ECI (energy consumption indicator), paper-based energy use information | influence on consumer behaviour when interacting with individual electrical appliances or undertaking domestic activities | Electricity 44 households, 12 months | Following types of behaviour people said they had modified as a result of participating in the study: using one appliance instead of another, reduction in hob cooking time | The average daily consumption for electric cooking of 1.30 kWh. The average reduction for households employing an ECI was 15%, | T.V. |
Appendix B: Questionnaire

Questionnaire: Consumers preferences in user interface design of energy displays

This questionnaire is carried out to analyse and find out efficient and valuable information for designing user interface of in-home energy display, which aids households to monitor and control their energy consumption more effectively. In-home energy displays are measurement units that provide households with real-time (near real-time) feedback on their energy consumption and allow them to behave with respect to energy conservation, thus less CO2 gas emissions.

What gender are you?
- Male
- Female

What is your age?
- under 25
- 26-35
- 36-45
- 46-55
- 56 and over

What is your occupation?
- Full-time employer
- Part-time employer
- Self-employer
- Unemployed
- Retired
- Student

What is your general attitude toward energy saving?
- Very positive – I actively save energy and believe I can make a difference
- Aware and positive, but it is not part of my current work day culture
- Partly energy aware; I take some action and occasionally pass on information to my colleagues
- Neutral, I may occasionally try to save energy
- Generally indifferent towards energy saving
What is your average energy consumption for a month?

- 1-10
- 11-50
- 51-100
- 101-200
- 200 and higher
- do not know

Would you like to have special in-home energy display, which represents explicit and accurate real-time energy consumption of your house?

- Yes, I would use it to save energy in my house
- Yes, just for interest
- Maybe, but do not have desire to have it
- No, I am fine with my current metering appliance

Which motivational factor from the followings can encourage you to act with respect to energy saving?

- setting goal on energy saving
- more explicit knowledge about energy tariffs
- comparisons between your energy consumption with your neighbors' or relatives' consumption
- monetary rewards
- realizing that you can produce less CO2 gas emission due to energy saving

What type of information from the followings do you prefer to see on the screen?

- energy consumption in kWh
- energy consumption in monetary rate
- rate of CO2 gas emission

What type of display do you prefer to use when monitoring energy consumption?

- numerical display (uses numbers)
- analogue display (uses graphics, diagrams, tables, etc)
- ambient display (uses lights, sounds)

Should energy display be colorful?

- Yes, it can aid consumers to interact with display frequently
- No, colorful display would disturb
- Does not matter colorful or not
Would you like to receive awareness, if your energy consumption increases? If yes, what type of awareness do you prefer to use?

- lights (e.g. red light - high consumption, yellow - medium consumption, green - normal/min consumption)
- popup messages on the screen
- sound awareness
- None, it is not effective

Which method from the followings do you think is more effective for dislaying?

- cumulative energy consumption
- separate energy consumption of each home appliance (e.g. washing machine, cooker, etc.)
- energy consumption of grouped appliances according to their purpose (e.g. ‘wet’ appliances: washing machine, dish washer, etc)
- energy consumption of grouped appliances according to their location (e.g. kitchen appliances: microwave oven, dish washer, etc.)

What type of additional information do you prefer to view on the screen?

- cumulative energy consumption of last week/month
- energy peak periods
- monetary rates of peak periods
- hints of energy savings
Appendix C: Interface Design

Figure a. Main Page

Figure b. Appliances Expenditure page
Figure c. Expenditure History page