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Balance Sheet Design and Study for Itemized Consumption Feedback and Load Monitoring

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The importance of consumption feedback is in making energy more visible and open to understanding and control.

The objective of this thesis study is to assess the potential of developing itemized consumption feedback through load disaggregation and propose an effective feedback presentation method to display the energy consumption and cost profile of electrical devices in a household. The feedback platform is planned to be a web based balance sheet which mainly utilizes device fingerprinting (Identification) results.

For the entire study, a two phase research approach was followed. The first phase is experimental, which focused on extensive electrical measurements and data analysis for a broader load classification which can be provided as an input for further load disaggregation techniques. The second phase gives emphasis to the need for developing a methodology to use the analysis results. One path of the methodologies studied further techniques of device fingerprinting and load classification, while the other branch of the study, which is presented here, deals with developing a feedback presentation method for calculating and providing disaggregated consumption and cost information. The measurement phase was conducted for several household appliances with a power quality analyzer (TOPAS instrument) and the data and electrical parameters were studied. MySQL 5.1.31 is used to build a database used by the balance sheet, Apache 2.2 is implemented as a server and PHP script language is applied for data processing adding dynamic features to the web based balance sheet. External data analysis was carried out using Microsoft Excel and Matlab tools as required.

Keywords: feedback, consumption, load monitoring, disaggregation, cost

FOREWORD

This Master thesis study is part of a research project entitled BeAware, which stands for 'Boosting Energy Awareness with Adaptive Real-time Environments'. The project is financially supported by the European Union and it includes industrial and academic partners from Finland, Sweden and Italy. Its objective is to raise the awareness of electric energy consumers towards near real time energy consumption. Hence, consumers are planned to be active followers and participants in monitoring their energy consumption by getting updated energy consumption feedback through their portable (hand held) devices such as mobile phones.

I hereby would like to take the opportunity to thank a few people for making this thesis possible. First of all, I would like to thank Prof. Matti Lehtonen for his guidance, time and constructive feedback, steering me into the right direction. Special thanks go out to my project partner Manyazewal Tesfayie whom it has been a pleasure to work with. I am also grateful for a friend and a colleague, Merkebu Zenebe (MSc), for his time and critical comments. From the non academic circle, Topi Mikkola, of a company involved in the BeAware project, has been cooperative enough for an efficient progress of the research study.

Furthermore, my parents, sisters and brothers should be given the credits for their continuous support and love as these give meaning to every step I take. This all would be incomplete without thanking God who watches over His children in every path of life.

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Solomon Nurga Biza

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1. INTRODUCTION

Most people have a vague understanding of how much electrical energy they are using for different purposes and what sort of measures can be taken to make a difference. The early studies on energy feedback carried out in the 1970s and 1980s were taken as an intervention in the normal order of activities [9]. Usually, Consumption profiles and feedback are provided by the utility at the total household level unless advanced monitoring techniques are implemented for load disaggregation. Monitoring Electrical consumption of distinct load categories has been a challenge till recent studies came up with promising results for device-level load monitoring in the beginning of the 1990's [1].Conventionally, Electric utilities informed customers their electrical cost with total monthly consumption bills. The Load monitoring systems, however, projected the potential to disaggregate loads into predefined categories and appliance types providing the opportunity to develop a system for an effective energy consumption feedback to the customer.

Itemized and recent consumption feedback of electrical devices will mainly benefit customers since they will be able to monitor their consumption and cost share which results in looking for the optimum condition for electrical devices to operate. These earlier studies also show that residential utility customers value accurate and easy-to understand information about their energy use and would like to receive more informative billing information [12]. On the other hand, utilities may use the recent consumption data for a timely load research and load forecasting purpose.

A web-based energy feedback model (balance sheet) is implemented in this study for residential appliances. The proposed model balance sheet provides information on electrical consumption as well as the cost shared by distinct categories of appliances. It was required primarily to revise various load monitoring and load classification methods to assess the potential of the balance sheet for device-level consumption feedback. The most dominant system discussed frequently for load monitoring and disaggregation techniques is the Non Intrusive Appliance Load Monitoring System (NIALMS). The principle of NIALMS is based on the discovery that, as electric appliances are turned on and off, the waveform of the total site load changes in predictable ways [2]. Since the NIALMS measuring unit monitors the total load at the service entry point, it does not require access to individual appliances. On the contrary, conventional techniques for appliance load monitoring are intrusive in nature as they involve either the installation of separate recording meters for each appliance or the installation of multi-channel recording meters that are equipped with a recording sensor per appliance.

The NIALMS approach is designed to monitor an electric circuit that contains a number of appliances which switch on and off independently [3]. By analyzing the current and voltage waveforms of the total load, NIALMS disaggregates this load and estimates the operational states of individual loads and their energy consumption. NIALMS is a relatively recent development, which was pioneered in the United States in the early eighties (George W. Hart et al. [3]). Similar works were also carried out in France by EDF (Electricite de France) in collaboration with Schlumberger Industries based on a monitoring principle similar to the system developed in the US [7].
The monitoring system by the NIALMS is based on unique operational electrical characteristics used to disaggregate the total load into individual devices. Two significant operational states are considered to determine unique electrical characteristics for load classification and more accurate energy consumption report: steady state and transient state of an appliance's operation [3].under steady state operation, the electrical parameters are further studied to be either of the fundamental frequency or harmonic frequencies. However studies on transient states indicate that advanced monitoring system with higher sampling frequency is required to detect patterns of transient shapes.

More importantly, besides the study on previous load monitoring systems, it was required to review the effectiveness of energy feedback methods implemented so far. In majority of the cases, residential energy use is invisible to the user [9].Effective methods of providing feedback on energy consumption to the customer enable householders to take important measures for the most favorable consumption trend and behavior. Electricity customers are hence allowed to know where their power consumption is going, what they can do to control usage, lower their bills and also help reduce their carbon footprint [11].

The review on NIALMS load monitoring techniques is briefly discussed next, which is followed by a detailed review section on feedback presentation methods for energy consumption.

1.1 Load monitoring techniques for Non Intrusive Appliance Load Monitoring Systems (NIALMS)

The first NIALMS algorithm was developed for two-state residential appliances in US at MIT (Massachusetts Institute of Technology) in collaboration with EPRI (Electric Power Research Institute) [5].The research [3] was mainly driven by the need to simplify the process of data collection of energy consumption that is used for load research by utilities. There were also other areas of interest such as detailed (itemized) energy consumption report, which is helpful to suggest ways to reduce consumption and hence cost. Supplementary targets include the detection of failed appliances based on their power consumption pattern and duty cycle.

For this study, the three main system components involved are the recorder, the master station and the analysis station. The NIALMS recorder is installed next to the existing energy meter and it records step changes in real and reactive power. Data from the recorder consists of interval data for the whole premise as well as event data consisting of the time and magnitude of load changes. The sampling rate is set at 2 kHz, and real and reactive power values are calculated three times per second. Recorded values are then stamped with their respective identifiers: date, time, Watt and VAr and then logged into memory. At specified time intervals, the whole-house watt-hour measurements are also stored into memory by the recorder. [5]

The Master Station is a personal computer on which the NIALMS Master Station software is loaded. Either on an automatic user-defined schedule or on demand, the recorder downloads all of these data to the Master Station over the public switched telephone network. [5] Using the time-based load data received from recorders, it generates the respective appliance specific load data. The system employed a database which includes a library of load models which are used for semi-automatic identification. The user selects the appliances in the premise from the library list and as the NIALMS algorithm processes the edge data, loads with characteristics matching those in the library are identified.

The Analysis Station software is a relational database application that performs processed data
query and presentation functions [6]. It retrieves user specified load data from the Master Station
database and uses it to review the load profiles and to create reports and graphs for further analysis and load monitoring[5].A beta-test was conducted to examine NIALMS hardware and software performance for two-state appliances under a wide variety of conditions.

The identification process was done either automatically by the software using a selected list of
appliances from the built-in library of load models or manually by reviewing the characteristics of a cluster that is left unnamed. Regarding the measurement of appliance load and energy-use, the NIALMS data was compared to the data collected from the parallel-metering (utility monitoring equipment), which was used as a reference for evaluating the accuracy of the NIALMS.

Below are presented some of the limitations of this NIALMS and the problems encountered during the beta-test period:

- There will be no ON or OFF events for NIALMS to detect if the device is in continuous operation all the time.
- NIALMS was not suitable for detecting small loads having real power consumption below 50W
- In the event that NIALMS misses an OFF edge, it will result in over measurement of energy
- In the event that NIALMS misses an ON edge, it will result in under measurement of energy
- Appliances using variable speed drives generate a large number of edges that mask other loads
- In the case of multi-state appliances, NIALMS is able to detect some or all of the individual components but the software is not able to aggregate them into a single appliance
- It couldn't distinguish between appliances having similar power consumption profiles

The other study, which implemented the NIALMS technique, was developed in Finland at VTT Technical Research Center [7]. It implemented a 3-phase power quality monitoring energy meter and it developed its own load identification algorithm that required a prior manual set up for the naming of appliances and building a signature library (the manual set up is a one-time intrusive activity in which signatures are observed and named as appliances are manually turned on and off) . The system utilized fundamental frequency signatures (ΔP, ΔQ) for edge detection and load identification.

Appliance data from the total load need to be analyzed with respect to reference data in order to identify specific appliances. Information about appliances to be identified from the total load is contained in the appliance register. This consists of:

- Name of the appliance group to which an appliance belongs (i.e. lighting, freezers etc.)
- Appliance on and off-state transition powers (signatures): dP_{ONi}, dQ_{ONi}, dP_{OFFi}, dQ_{OFFi}
- Appliance model (two or multi-state appliance)
- The phase to which an appliance is connected (R, S, T or 3-phase)
- Typical on-cycle time in seconds (<1800 sec, <3600 sec or >3600 sec) [7]

In addition, the difference between on and off-state power transitions (due to temperature rise or cooling compressors) can be used for appliance identification. States of transition powers are assigned numbers in the register and states of appliances of the same group are given consecutive numbers; then grouped appliances are added to form one appliance load curve.

Small resistive lighting appliances do not have individual cluster but the consumed power values are scattered between 50 W and 210 W along the real power axis. Similarly, fluorescent lamps with power factor correction circuitry, television sets and personal computers appear as nearly resistive loads and they are all grouped as small appliances in the appliance register. Clusters of common fluorescent lamps were defined in the appliance register as an area on the PQ plane where $30W \leq dP \leq 70W$ and $70VAr \leq dQ \leq 10VAr$ (similarly for off-cluster with negative signs).

The field test was conducted in 1996 at a single house located in Helsinki, consisting of a number of distinct household appliances. Based on the data obtained the NIALMS performance was evaluated using two criteria. The first criterion defined the accuracy of estimating daily energy consumption by comparing the measurements with parallel metering equipment. The second criterion (a modification of the first one) described the accuracy of estimating the energy consumption over the whole period (a week or a month). [7]

The limitations for this system developed at VTT include misinterpretation of events belonging to multistate devices, less accuracy in detecting small-power events while a heavy load operates and the need for a laptop PC since the event recorder was not integrated into the KWh.

An enhanced version (Commercial Non Intrusive Load Monitoring System - CNILMS) of the residential NIALMS was later developed for monitoring loads at commercial buildings with three-phase service. The main features and capabilities included were that it was configured for three-phase (grounded, 4-wire star connected) loads monitoring, which was accompanied by new hardware and expansion of the processing software, and that it was designed to monitor current and voltage at the customer site to recognize loads not only based on power consumption, but also using power factor (phase difference between current and voltage).

Four CNILMS recorders and conventional end-use measurement devices were installed in parallel on many of the end-use loads. Data comparison was done based on daily energy consumption measured by the parallel recorders and the CNILMS recorder. The data (in kWh) for each load were partitioned into ninety six 15-minute intervals per day. Then total daily energy consumption (sum of all intervals) was used for computing percentage error. [8]

Percentage error =

[(daily CNILMS kWh) - (daily parallel kWh)] / (daily parallel kWh)*100%

The value of this error indicates the relative performance of CNILMS as compared to the Parallel metering equipment. The CNILMS had limitations of accurately calculating the energy consumption of loads with variable thermal characteristics (e.g. refrigerators), combining individual loads of within an appliance to one particular load and identifying simultaneously operating loads.

Later, advanced Non Intrusive Load Monitoring techniques were studied for obtaining more electrical characteristics to be used in load disaggregation. Evaluating higher harmonics characteristics and studies on transient nature of appliances are the primary methods tested for better load disaggregation. Steady-state load monitoring was claimed to be effective for residential and small commercial buildings due to lower number of events generated and lower number and variety of loads. However, medium to large size commercial and industrial facilities demand advanced approaches due to "high rates of event generation, load balancing and power factor correction". [10]

1.2 Feedback on energy consumption

As discussed earlier since most domestic energy use is invisible to the user, users are not well aware of the energy consumed for different purposes [9].Thus consumption feedback has the benefit of making energy consumption more visible, predictable and manageable. Users are then provided the chance to update their consumption trend and consumption behavior accordingly. It is stated that the first studies in the 1970's established the consumption feedback mostly via display monitors. The feedback had measurable effects and encouraged further studies on feedback systems alone or in combination with other processes [9].Feedback is then taken as a learning tool which allows energy users to teach themselves through observation and experimentation.

The feedback methods are studied in two categories as direct feedback methods and indirect feedback methods. Direct feedbacks are immediate feedbacks directly from the energy meter or from an associated display monitor. However, in indirect feedbacks the feedback is processed in a preferred way before reaching the energy user usually via billing. [9][11]

According to [9], Savings from direct feedback are normally ranging from 5-15 %.The energy meter is expected to provide a clearly-understood point of reference for improved billing and display. Either an independent display is used or the meter is set up at a visible spot within the customer residence. High energy users are stated to respond more than low energy users to direct feedback.

Indirect feedback is more convenient to demonstrate the effects of the measures taken by the energy user. The savings from indirect feedback are stated to have the range from 0 to 10 % and it is reported that feedback which is disaggregated by end-use at the electricity meter is comparatively expensive and complicated to supply [9].

One of the earlier feedback experiments involved a note posted on the consumer's kitchen window each morning, telling him or her how the previous day's consumption looks when compared with some reference level. The experiment proved that feedback can have measurable effects on consumption behavior. Prior studies show that the more specific and relevant the energy information is to the household the more effective it is in achieving energy savings [12].

It was stated that previous researches in energy conservation in family households show that per-household savings up to 30% can be realized through consumer behavior changes alone.[14][15] From various study results, billing information was reported to be of poor quality lacking decisive information for the customer. According to the study results from [16], billing information is often poorly understood and interpreted by consumers and does not address the information needs of many bill payers. It is also stated that because energy services (heat, light, etc.) are billed in the aggregate and in unfamiliar units of kilowatt hours (kWh), consumers have no easy mechanisms for learning about their home's energy use making the case for disaggregated billing information [12].

1.2.1 Comparative electric utility billing information

Studies for informative billing practiced in Norway and US proved how customers appreciated improved accuracy and extra information. The studies are focused on feedback that shows each customer how his billed energy use compares to others in similar residential setups. It is reported that the customers began to read their bills more frequently and with more understanding which caused them to alter their consumption behavior [9][12].The experiment in Norway was conducted and presented with discussion for two main reasons. These two reasons are to make households aware of their energy use, providing a better platform for energy savings, and to improve communications between the utility and the energy consumer [12].The improved billing information through the comparative billing component provides individualized energy information for a mass audience at a low cost, using the already existing utility bill. Comparative feedback is implemented in the studies where a customer's consumption profile is compared with another customer or customer group.

The two major energy information projects were stated to be conducted using funds from institutions in US and Norway [12]. The initiative for both projects is the outcome of previous researches which generally implied that existing utility bills are deficient. The implemented comparative billing information is a relative performance measure and works only in those cases where the consumer is able to recognize the relationship between behavior and outcome.

In the study conducted in Norway, the test included information disaggregated end use where the consumer was informed on how much energy goes to significant devices within the residence. It is also reported that since devices are not metered individually there exist misconceptions about the energy shared by different end uses [12].For instance, other previous studies claimed that it is a common misconception to assume that more energy goes to lighting and cooking than the actual share. Similarly the researches state that less energy was wrongly assumed to be consumed by heating and cooling. Thus the objective of the disaggregation was to correct the misunderstandings and raise awareness on consumption of significant loads as space heater and water heater.

At the study in US, the 'neighborhood comparison' approach is used where the comparison group consists all of the households in a given neighborhood, combined with house size and appliance mix [12]. Feedback recipients in the Norway study were categorized according to the number of people in the household, type of dwelling, house size, use of electric heating (three categories: 100% electric, mix of electric and other, no electric), and hot water either included or excluded from the household electricity bill [12].

In US the research project included a study on two Mid-Western utilities (Traer and Amana), and their customers. During the first stage, a face-to-face interview and a mail survey were conducted, followed by a second stage of interviewing Traer's customers after they received the billing graphic for two months. Next, the utilities provided graphic billing information for 3 years (Traer) and 1 year (Amana) and face-to-face interviews with the customers were followed with. In the study, main focus was given to the evaluation results of the program leading eventually to a comparative graph implemented by the two utilities. [12]

The study in Norway evaluated the effects of comparative feedback and disaggregated end use information provided. The initiative was from the positive results from implementation of historical feedback at the Norwegian utility (Stavanger energy which is now Lyse energy).Stavanger's success with the program has been reported and confirmed with the 8% electricity savings. This has led to national mandate for all utilities to provide the billing information for customers. However, in this study three types of displays were chosen to visualize the comparison; i.e.

i) a linear version which placed the recipient's consumption in relation to the highest and lowest energy consumers in the group
ii) a normal (bell) curve version which shows not only the placement, but the distribution of households within the group
iii) a variation on the normal curve, in which the shape of the curve is represented with figures of small houses. This display is similar to the display preferred in the U.S. Study.

In Norway by evaluating the disaggregated end use information, it was found that the pie chart version was more favored in all of the focus groups over the bar chart. The pie chart is stated to be easier to interpret and to provide a convenient overview of the disaggregation. Six appliance categories were selected to be included in the display: electric space heating, other space heating, water heating, lighting, kitchen appliances and washing machine and others.

In the study in US at the two utilities mentioned above (Traer and Amana), 4% of the respondents said they could not understand the graph. Majority of the 4% were older with an average age of 67 years.

Table 1.Feedback evaluation results at the US utilities

Graph Comprehension: Ability to make comparison	Percentage of non-missing
Graph too difficult to understand	4%
Not enough information	10%
Did not answer, missing	N/A
Made comparison (Lower, same, or higher bill)	83%

On the other hand, on the study conducted in Norway 16% of the customers said it was difficult to understand the normal (comparative) curve while 77% understood it conveniently. Results from the linear graph implied that the customers were more comfortable with the linear graph than the comparative graph. Only 9% of the customers found the linear curve difficult to understand and 83% of the customers did not find it difficult to comprehend. [12]

The US evaluation data proved that respondents appreciate greatly the comparative billing information provided, with a promising potential to understand it and to adopt energy conservation measures. Of the total focus group, 64% reported that they have made energy efficiency changes as a result of receiving the comparative graph and an overlapping 40% had similar intentions. Similarly in Norway, the information from comparison with other customers and disaggregation of energy end uses was highly valued by customers of the Stavanger's utility.

Table 2.Customer feedback evaluation in Stavanger energy, Norway

Stavanger: Level of interest	Normal curve	Linear
Agree/completely agree: The information is useful	88%	83%
Disagree/completely disagree: The information is not interesting	85%	88%
I am interested in receiving the information should it be offered	94%	98%

The customer evaluations in Stavanger gave a number of strong indications that the disaggregation is an information measure people are very interested in and that it has the desired pedagogical effects [12].Overall the two major research projects highlighted the importance and the growing interest towards informative and comparative billing with special interest in disaggregated reports of energy consumption.

1.2.2 Consumer preference for feedback

Another study in UK was conducted with the objective to identify and describe a shortlist of the most appropriate and effective methods for presenting consumption feedback to consumers [4].

According to [9], the study result shows some distrust of comparative feedback which is discussed above. It is stated that customers were suspicious about the validity of their comparison group but valued historical feedback which compared their recent consumption with that in previous billing periods.

The research team followed two main methodologies for the study. The first is to investigate the consumer preference through understanding and response for a specified focus group and different types of feedback presentations. The other methodology is to explore with the six energy utilities the feasibility and deliverability of the feedback options and utilities' interest in this issue. Three focus groups were selected in different locations, i.e. Bristol, Ipswich and Leeds. In the study process the investigation included examining current engagement with, and views on customer bills and consumption levels of customers. The investigation also included examining the perspectives of energy suppliers and their involvement in energy saving, understanding of energy saving techniques and levels of action and motivation to act, and reactions to proposed feedback options. [4]

A number of the proposed concepts for feedback were not appreciated by the customers (members of the focus group).For instance the bar chart comparing a customer's consumption with an 'average consumption' per day was rejected since customers were not aware and in favor of the method the average is calculated. The other proposed bar chart comparison which compared a customer's consumption with other residents in the neighborhood was also disliked by the focus group. Focus group comments implied that customer's are rather interested in their own energy consumption profile.

On the other hand, it is stated that some of the proposed concepts for energy feedback were appreciated by the focus group. This included simple bar charts with historical data comparing the current year quarter consumption with last year's similar quarter consumption. The other feature appreciated was a bar chart series, with each bar representing the consumption within three consecutive months of the year.

1.2.3 Feedback types and effectiveness

One of the non sophisticated feedback methods is the use of basic metering without separate direct display monitors. Here a householder is expected to record consumption from one meter reading to the next and use the meter to check the accuracy of bills or reports. This feedback method requires commitment from the householder to reading the meter regularly. [9] The other alternative implemented is the use of key meters and keypad meters promoting prepayment. Key-meters are stated to be semi smart in that they allow transfer of information such as tariff changes and meter reading data to and from the key-code at the payment shop. Around 25% of North Ireland households use keypad meters buying credit from a nearby outlet and keying a 20 digit code into their meter located in a chosen room. Savings for all keypad customers are estimated at 3%. [9][17]

Considering direct displays on monitors separate from the meter, is another option for feedback presentation. Here with a free-standing display the meter can be left alone once a transponder is attached. Customers can look at the displays for instantaneous or previous information. On a trial discussed at [18], over half of the interviewed householders wanted to have such a display permanently. For relatively simple displays, the savings are stated to be typically of the order of 10% [9].

The other feedback type employs TVs and PCs for display. A more complex interactive online display tested in Japan gave an 18% electricity savings within 9 months trial for 10 householders [19].A similar study using interactive web page for 137 Dutch households is reported to achieve an 8.5 % electricity saving.

A model for generating household electricity load profiles is discussed in [27]. Here, the load model used data available in public reports and statistics as an input for analysis, model training and verification. The study publication claims that with a basic demand side management

(DSM) the daily peak loads can be reduced 7.2% in average. In addition, With a more strict DSM methods the peak load at the yearly peak day can be completely leveled with 42% peak reduction and sudden three hour loss of load can be compensated with 61% mean load reduction. It is stated that the accuracy of the end-use models depends on the availability of grass-root level consumption details. The main limitation for bottom-up (appliance to households) methods was an extensive need of data about the consumers or their appliances and generally the households.

Disaggregated feedback is a more sophisticated and recently popular method which requires the use of advanced monitoring techniques for individual appliances. It is reported that from 1000 Norwegian households who were given a pie chart on their bill displaying breakdown of six main domestic loads, 81% of respondents thought it useful and 38% of them learned something new [9].Though it is stated that end-use disaggregation can be carried out by identifying appliance signatures, this method was classified as unfeasibly expensive for everyday use by householders [20] [9].

Ambient displays, which do not show text or numbers, are alternatively used as feedback presentation methods. Ambient displays simply alert the householder in case significant change occurs or is about to occur to the householder’s electricity supply. A flashing light was used to alert a sample of American householders recommending the householder to turn off the air-conditioning and to open windows for cooling depending on the outdoor temperature. During a test period of 3 weeks the feedback gave savings of 16% [21].

Informative billing, which is an enhanced version of standard utility billing, is also studied as a feedback method. Here bills can be adapted to show a more detailed analysis of the householder’s consumption trends over time. The comparative billing research projects discussed in section 1.2.1 are part of the feedback presentation method through informative billing.

Generally the increase in awareness or knowledge of electrical energy consumption through effective feedback presentation methods results in visible changes in energy-use behavior and a decrease in energy consumption. Though the acceptance of these feedback methods has been studied and presented in percentages, the data still show that a more updated and convenient feedback presentation method is not yet studied and provided for householders.

Consumption feedback presented to householders should not provide merely consumption information in the technical and conventional format or in KWh. The feedback presented ought to be immediately translatable into a conservation step other than simply cutting electricity use. It must be related to the conservation goal selected and tailored to the household's actual consumption. The feedback presented should be as close as possible to the users' actions so that it is easier to affect specific behavioral intentions than general ones. Moreover the user needs to understand which steps would fill the gap between the actual existing state and the targeted one. [22]

1.3 Consumption Feedback by the Balance Sheet

Part of the project study which is discussed in this paper proposes a web-based, dynamic feedback presentation method to householders. The objective is to address the requirements for an effective and user friendly type of feedback, which can be accessed from mobile devices with an internet feature. This web-based feedback presentation method is stated as a Balance Sheet for electrical energy consumption.

In its original sense, a balance sheet or statement of financial position is a summary of what a person or an organization owns and owes at a certain date [23]. A balance sheet is often described as a snapshot of one's financial condition. By borrowing this financial term, important and cost-related information on total energy consumption and contribution (share) of distinct classes of equipments is provided. Hence, in the adapted term a "balance sheet for power consumption", there is a suitable way of informing:

- overall energy usage of a specific household
- which device is responsible for a certain share of the energy usage
- how much a customer owes an electric utility
- the corresponding recent and previous consumption

Consequently, a user will be able to trace periodically electrical cost and consumption per appliance or per small group of appliances. This helps the customer to monitor the consumption of appliances independently in addition to being aware of the total energy usage. Moreover, this information can be reported in itemized bill format to the customer by the electric utility. A customer can then observe and reduce his costs by recognizing appliances with higher consumption or with operational problems. A balance sheet is often presented alongside one for a different point in time (typically the previous period) for comparison. Therefore, hourly based information can be an input for daily, weekly or monthly analysis and information.

Subsequent to finding a unique finger print for appliances and developing a system for using this record for real-time identification of appliances, every identified appliance's data is transferred to a central database. In addition to the identity of appliances, the data include the corresponding power consumption and associated time information. The balance sheet was initially planned to employ online data extracting and analysis tools to provide a valuable and updated summary of the power consumption and corresponding cost of appliance consumption. Depending on a user's inquiry, this balance sheet information has the potential to be presented in different tabular and graphical display formats.

The balance sheet provides the advantage of presenting disaggregated energy consumption of distinct equipment classes from total energy usage of a household. These classes of equipments are categorized mainly depending on the analysis results from the load monitoring and finger print identification process, which figures out unique consumption properties for individual appliances.

Overall, the major objectives of the entire project research and study are to practically test and assess the monitoring techniques for load disaggregation to an appliance level, and to present the related significant consumption feedback effectively to the customer within the appropriate predefined time interval.

The study on the web based Balance Sheet is important since the recorded parameters from the fingerprint identification process need to be extracted from the database and then be analyzed for presentation in a brief and informative manner.

2. Survey for load disaggregation and feedback

In advance to developing a feedback presentation method, the first task in the study was to evaluate the practical possibilities and limitations of load classification using electrical characteristics from measurements. The feedback mechanism can then be designed according to the extent to which household appliances can be categorized.

A wireless sensor, which is installed between an appliance plug and a power supply plug-in point, is primarily part of the research project. The sensor is designed to send data which includes measured electrical parameters of an appliance to a base-station, which is a measurement gateway installed at each household. The entire project aims in the long term to install a single sensor connected with several appliances where load disaggregation or device fingerprinting techniques are applied to distinguish between each appliance and report on their recent consumption. The results will be provided to the feedback system for presentation.

An extensive electrical measurement of typical residential appliances is conducted at the first phase. The resulting analysis and study was aimed at exploring various electrical characteristics of household appliances that have the potential to be used as load disaggregation or identification techniques based on the measuring capacity of the wireless sensing device. On the other hand, the analysis results were expected to confirm whether the future balance sheet features are capable of providing the respective share of each category of appliance and aggregate energy consumption report.

2.1 Measurements for load disaggregation and feedback

The fundamental objective of the extensive series of measurements is to obtain a technical load classification, which entails the monitoring of operational electrical characteristics of individual household appliances. From the results obtained, it is possible to examine the operating behavior of different loads and categorize them accordingly. This load classification is intended to serve as the basis for the fingerprinting and balance sheet calculation tasks.

All the measurements discussed in this thesis report were recorded using TOPAS 1000 Power Quality Analyzer instrument, a product of LEM NORMA GmbH, Austria [23]. It has several fields of application including power quality analysis as per EN 50160 standard. It is also capable of measuring harmonics up to 50th order. The unit has 8 electrically isolated analogue inputs that can be used for current and voltage measurement. Each channel is equipped with a 16-bit analogue-to-digital converter. Sampling of all channels is synchronous based on a common clock signal. The sampling rate is synchronized with the line frequency and is typically 6400 Hz at a 50 Hz line. The measurement methods mainly used in this work were RMS values over 3 second and 10 minute intervals, amplitude spectrums and sample values (digital oscilloscope).

Voltage sensor 400 V –

Measuring range 4...680 V
Accuracy / phase angle 0.11% / 0.005° (45 Hz…65 Hz)
0, 15% / 0,034° (65Hz ...1kHz)
0, 2% / 0,125° (1 kHz…3 kHz)
Frequency range 45 Hz ...3 kHz

Clip-on current sensor 100/10 A –

Measuring range 100 mA...120 A / 100 mA...12 A
Accuracy / phase angle 0,5% / 3,5°
Frequency range 45 Hz ...10 kHz

Clip-on current sensor 5/1 A –

Measuring range 50 mA…14 A / 50 mA...2,8 A
Accuracy / phase angle 0,5% / 30
Frequency range 40 Hz ... 5 kHz

Following the examination of sample test results and necessary revision of the measurement settings, the actual measurements began in the first week of January 2010 and were conducted over a seven week period. The list of appliances that were covered in this phase is provided in Appendix III. Most of the measurements were performed at four locations in Espoo city, Finland: Electrical and Communications Engineering buildings at Otakaari 5, Lighting Laboratory at Otakaari 7, student housings at Jämerantäival and other residences at Espoon Keskus.

Data was recorded temporarily in the TOPAS memory space (up to 500MB) and was then fetched to a laptop PC through direct Ethernet connection using the TOPAS software installed on the laptop.

The TOPAS settings to obtain data for transient characteristics were not activated. This is due to the fact that the prototype for the future BeAware plug in sensor has a sampling rate of 1 kHz whereas the sampling frequency of the TOPAS for transient data measurement ranges from 100 kHz to 10 MHz.

The required data is then exported from the *.def file format to Microsoft Excel for further analysis. The Excel spreadsheet analysis for an appliance includes:

- Information on the rating and model of the appliance,

- 10-minute average or long interval values while the appliance is under steady state operation,
- Changes in active and reactive power during switch on (dPon, dQon) and switch off (dPoff, dQoff) by providing one second samples for a total duration of 25 seconds,
- Harmonic contents data for current, active power and reactive power up to 25th order
- Total harmonic distortion values for the duration of normal operation up to 50th order and alternatively up to the 25th order
- Duration of ON-cycle for appliances with cyclic operation

The excel measurement and analysis files are compiled and recorded for every measured appliance. On the other hand, even if they were included in the appliances' list, a number of appliances were not measured mainly due to the lack of access to socket points. This includes water heater, air conditioner, heat pump and cloth dryer. The devices without accessible socket points are directly connected to the mains power supply system and hence do not allow the connection of the sensors of the measuring instrument.

2.2 Load classification for monitoring appliances

The measurement phase provided data which can be analyzed to produce an initial broader classification of common household appliances. The classification of appliances based on the measured electrical characteristics is vital to the process of building a library of load signatures for disaggregation, which can serve as the basis for the implementation of load identification, load monitoring and disaggregated feedback systems. Load signatures are determined by:

- The nature of electrical components of an appliance,
- The appliance's operational characteristics (cyclic operation, sequence of tasks…),
- The appliance's power supply type (particularly electronic power supplies)

In principle, the load library shall include a wide range of appliances but due to the existence of a large number of electrical loads, it is impractical to collect the signatures of all types of appliances. Nevertheless, appliances can be grouped by observing their similar electrical characteristics with each other even if they may serve different functions from the user's point of view [24].

According to the methods presented in [24] and [25], most household appliances can be classified as resistive, motor-driven, electronic or general inductive loads. Based on this approach and the measurement data collected and analyzed from a number of household and office appliances, a first step load classification was presented as follows:

2.2.1 Resistive loads

This group consists of appliances which are mainly utilized for heating and lighting purposes. They operate at a power factor close to unity (both fundamental PF and total PF) and possess very low levels of harmonic current contents, usually less than 5% Total Harmonic Distortion (THD_I). Appliances such as electric stove, incandescent lamp, space heater and coffee maker belong to this group of appliances.

From an operation point of view, these resistive loads can be subdivided as:

- Continuously operating (electric cooking plate and incandescent lamp) or
- Appliances changing their operating states alternatively depending on the setting of their thermostat (space heater and coffee maker)

2.2.2 Electronic loads

A large number of household appliances are powered up by electronic power supply units, mainly using the switch mode power supply (SMPS) type. The main purpose nowadays for using SMPS in common loads is that it provides improvement in load efficiency and controllability. However, its undesirable effect is an increase in the propagation of harmonic currents back to the utility grid [26].
A majority of these appliances exhibit a total power factor (TPF) that is significantly smaller than the fundamental power factor (FPF) due to the presence of harmonics. They are also characterized by high levels of THD_I and odd-numbered harmonic contents, specially the third and fifth harmonic currents. Appliances such as personal computers and their display units, television sets, compact fluorescent lamps and home entertainment system belong to this group of appliances.

2.2.3 Motor loads

This category includes motor-driven and pump-operated appliances such as vacuum cleaners, fans, refrigerators and freezers. The operation of these loads requires significant amount of reactive power and it also causes current distortion but with lesser impact as compared to electronic devices.

Appliances like dish washers and cloth washing machines are also motor-driven but in addition they consist of heating elements. In the case of dish washers, they can be considered as two-state appliances composed of individual loads (motors and resistors) that switch on and off independently. On the other hand, cloth washers are considered as multi-state appliances because there is a possibility that their components can operate simultaneously (for example drum rotating motor and heating resistor functioning at the same time) [7].

2.2.4 General inductive loads

Appliances in this category exhibit similar behavior like motor loads except the fact that their major components are not motor-driven. They possess a current spectrum dominated by the third harmonic current and a THD in the range of 15-30%.Two appliances that belong to this group are fluorescent lamps consisting of magnetic ballasts (without power factor correction) and microwave ovens.

Eventually With the exception of the devices without socket points (directly connected to the power supply system), the data for each appliance was organized for further analyses to assess the potential for advanced device-level load disaggregation. However, in this thesis study the feedback presentation method (balance sheet) is discussed mainly and further fingerprinting techniques are part of another branch of the entire study which is conducted and presented in details separately. As to the implications of this parallel study, there is a high potential of device-level load disaggregation. Hence, the proposed feedback presentation method can be designed to present appliance level reports rather than broader categories.

3. PROPOSED FEEDBACK PRESENTATION

The historical and indirect feedback presentation method was proposed and designed to be a web-based application presenting processed aggregate and appliance level consumption reports. It is discussed previously that the objective is to address the requirements for an effective and user friendly type of feedback, which can be accessed from mobile devices with an internet feature.

The selection for the type of feedback presentation was followed by the first phase of designing a prototype for the presentation method. Primarily, the layout for data or information handling structure of a web based balance sheet was developed. Then a sample database with expected tables and contents was created. At the end of this initial phase, the first version of data processing calculations was implemented.

3.1 Layout development

The prototype plug-in sensors acquire recent electrical measurements at the appliance level. Then selected parameters from the electrical measurements are wirelessly transferred to the base station. During the study, main meter measurements of an entire household and a number of fuse-meter measurements were also sent to the base station data.

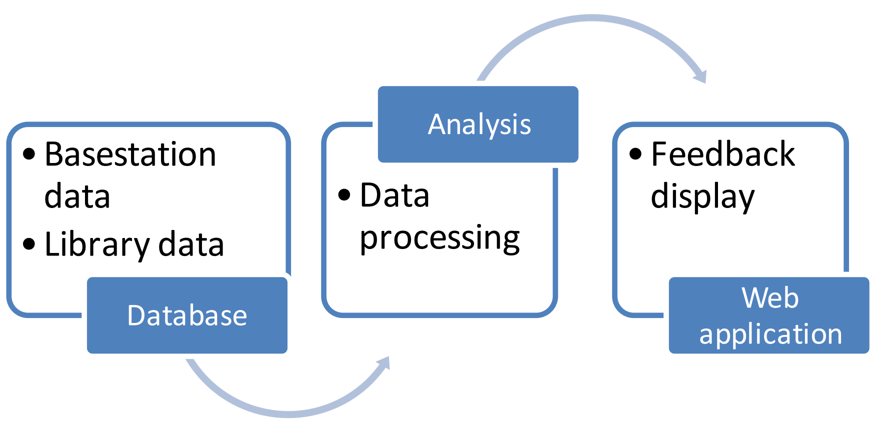


Fig.1 Data handling structure

3.2 Base station data

The overall data handling structure is as shown in fig.1. The base station records (receives) the main meter, fuse meter and socket level readings. The main meter reading is to be taken separately in the balance sheet from the fuse meter readings. Then since this main meter reading can be calculated as a sum of the fuse meter readings, the sum is to be compared with the original main meter reading. In normal conditions where all fuses are measured, the readings of the fuse meters would be summed to give the main meter reading. And if there are unmeasured or defective fuses the main- meter reading exceeds the sum from the fuse meters. As part of the feedback presentation, the layout included a table displaying these comparisons and corresponding comments. This Case is considered in Table 1 (at Fig. 3) of the prototype for the web-based balance-sheet.

Similarly, the fuse meter reading is important to sort out permanent loads without socket points (directly connected to the fuse-panels).This is obtained from the difference between the fuse meter reading and sum of socket (sensor) readings installed to this specific fuse line. When all loads connected to a fuse meter are having socket points monitored by sensors, then the sum from the sensor readings equals the particular fuse meter reading. Otherwise there is a load connected directly to the fuse-panel. Since the feedback presentation method is to be designed based on sensor information at the appliance level, other devices which are not monitored by sensors will be sorted out and studied to be presented on the balance sheet. Parallely, this Case is considered in Table 2 (at Fig. 3) of the webpage for balance sheet.

3.3 Library data

The library data is part of the database with previously gathered offline information. It is proposed to provide data to be included in tables of the database for:

-Predefined values of an electrical appliance, e.g. power consumption rating of devices

-Required user’s information associated with the household being monitored (e.g. user id, registered sensor ids with user’s location),

-Sensor-fuse combination where sensor IDs connected to a particular fuse line are known and registered.

3.4 Database

The database included in the layout consists of tables having data which can provide significant inputs to the balance sheet calculation. Proposed and sample tables of the model database were listed to carry on with developing a prototype for the web-based balance sheet. The following table shows the tables and data fields proposed to be included within the database.

Table 3: Proposed tables for the model database and balance-sheet

Proposed Table name	**Data to be included in the table**
Energy_meters	Hourly record of the main meter and fuse meters' energy consumption readings with corresponding dates.
Sockets	Sensor IDs and hourly consumption readings of sensors with associated dates
Appliance_data	Entire data from the sensor
Daily_ data	Daily energy consumption with dates
Socketfuse_info	Sensor IDs and the particular fuse they are connected to
Appliance_info	Appliance code, appliance name and appliance type
User_info	User id, user password, sensor IDs owned by this user and location

For the prototype of the Balance Sheet, the tables used are total-energy, energy_meters, sockets and socket-fuse info. Though it is planned to enhance the feature of the sensor to be connected with more than one appliance, the current sensor supports only a single appliance connection. Hence it is perceived that one socket point represents a single sensor connected to an individual appliance.

3.5 Data processing of measurement results

It was required to determine a data processing mechanism to process the information in the database before being displayed as feedback.PHP script language is selected to be used in supporting the data processing and the dynamic feature of the balance sheet. The balance sheet retrieves data to be processed from the database as well as from the user-input to display the corresponding results as an output.

PHP (Hypertext Preprocessor) is a popular general-purpose server side scripting language which can be embedded into HTML to create a wide variety of mini-applications as well as used to build large-scale complex applications. It is a language that was originally designed for web development to produce dynamic web pages, to have them be customizable and contain real time data. Its advantage over client side programs is that it runs on the web server rather than on the viewer's PC. [28]

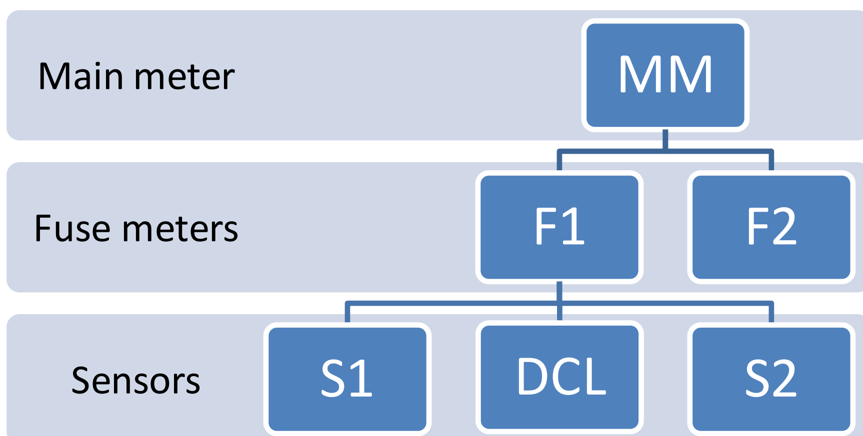


Fig.2 Basic measurement structure for data processing with Directly Connected Load (DCL)

Subsequent to deciding on the layout and data processing mechanism, focus was given to developing the prototype of the balance sheet with the required features. The web application for the prototype was initially to display hourly/daily energy consumption of an entire household and to display status of the fuse-meters and status of the plugged-in sensors. The option is given on a drop down list for selecting hourly or daily profile display. For the hourly/daily option, a bar chart is used to display the hourly/daily energy consumption of the current date/days of the week. On the other hand, two tables show whether valid measurement readings are obtained or not from the fuse-meters and the sensors. A pie chart was also designed to be included in the display to report on the recent consumption share of the appliances in a household. On the other hand, the current date's consumption cost of the entire household and the individual cost due to the identified appliances was planned to be displayed separately on the web-page.

Table 1 of figure 3 (APP.III) Table 2 (APP.II)

Fig.3 Designed prototype for feedback presentation using web-based Balance Sheet.

The snapshot displayed above presents the general layout of the proposed web-based feedback. The individual elements of the feedback page and the related calculations are presented and discussed hereafter in detail.

Following the design, individual elements of the feedback page were analyzed and codes were written to establish a system for actual data processing and display. For the first table displayed on the balance sheet (Table 1 in the left or App. II), data from the database is used as an input to process the contents of Table 1.The data processing takes place in the PHP script language and sum of the fuse-meter readings is compared with the main-meter reading for every previous hour. A related comment is then displayed accordingly. When a fuse-meter is commented as not being measured, either the specific fuse line is not installed with a fuse-meter or the installed fuse meter has become defective.

<u>Table 1-Main meter and Fuse meters (App. III)</u>

Data processing steps followed to obtain Table 1 contents of the balance sheet

1.Select and fetch all data of main-meter and fuse-meters from the table energy_meters where the corresponding incoming value of the date matches with the current date.

2.Extract the time stamps, the main meter and fuse meter readings for different time stamps.

3.Sum the fuse meter readings to have the total hourly consumption

4.Compare the main meter reading with the sum of the fuse meters

5.Take a remark* depending on the result from step 4

6.Display the time, main meter and fuse meters' readings with corresponding remarks.

*When the main meter reading is not equal to the sum of the fuse meters or when it exceeds the sum of the fuse meters, the remark is 'There are unmeasured fuses'. Otherwise the remark is 'all fuses are measured'.

Similarly Table 2 displays hourly fuse meter readings (for a specific fuse line) with consumption readings for appliances installed to this fuse line. Here the resulting remarks from the data processing and comparison, inform whether all devices are connected to plug-in sensors or not. This aids to observe loads which are not monitored by plug-in sensors and which are directly connected to the upper layer (fuse line).

Table 2- Fuse meter 1 and sockets (sensors) connected to Fuse-1 (App. II)

Data processing steps followed to obtain Table 2 contents

1. Select and fetch sensor ids from the library where the sensors are registered to
   be connected to Fuse meter 1(fuse line 1), from the table SocketFuse-info.

2. Fetch incoming data from the sensors (sockets)

3. Select sensor ids matching the ids retrieved in step 1

4. Extract the corresponding time when a match is found

5. Sum the energy values for sensors having energy data at this particular time

6. Compare the sum with the total energy reading of Fuse 1, which is taken from the other table named energy_meters.

7. Take a remark* from the result in step 6

8. Display the time, fuse meter reading and sensors' reading with the corresponding remark. (When fuse meter 1 reading is different from zero)

* When Fuse 1 reading exceeds the sum, there are loads being connected to Fuse 1 directly and without any socket points. These loads are most likely to be permanent loads. And the remark is 'permanent loads connected to fuse'. Otherwise the remark is 'all loads are connected to sockets'.

For the bar chart showing hourly and daily profiles on fig. 3

1. The default display uses hourly option to fetch hourly consumption and the specific time stamp data from main-meter column in the energy_meters table. Here, on the prototype, data of the current date is only considered as an input to the bar chart.

2. When the user chooses the daily option, data from the daily_data table is fetched and it provides dates and corresponding energy values for the chart.

Similarly, this feature has the potential to include monthly consumption data to display monthly profiles as one option in the bar chart.

3.6 Web application

HTML codes for web page programming and JavaScript features for graphical representation were used for the balance sheet. Other than the two processed tables, the web page displays the current date via PHP script language and graphic chart information by means of JavaScript. The later is displayed on the balance sheet page as a bar chart of the energy consumption profile using data from the database. The user will be provided with options to view this graphic, recent data as hourly, daily or monthly profile.

Taking the user's choice as an input, the balance sheet web page is able to display the information showing hourly, daily and monthly consumption profiles. At the prototype level, it displays hourly and daily profiles using data from tables in the database.

Following the first phase for layout and prototype development, further steps to be taken were listed out. The planned activities include upgrading data processing calculations. The other major task was integrating the balance sheet with further load classification methods. Then this aids while trying to calculate the share of various loads in the entire consumption.
The shares for each category of appliance was planned to be displayed using percentages on a pie chart. The other activity listed to be performed was processing cost related information for disaggregated energy consumption feedback.

4. CONSUMPTION AND COST SHARES BY THE BALANCE SHEET

Having selected previously appliance-level consumption feedback, the consumption share is simulated with a display of a model pie chart on the balance sheet. The programming codes are written to calculate consumption and cost shares of individual appliances [App. V]. Additionally, replacing sample database variable values with actual data from measurements was on progress at this phase. Eventually a Classifying method or structure is proposed for sorting out directly connected (permanent) loads.

4.1 Balance sheet Calculations

At the first phase, the balance sheet prototype mainly calculated and compared sensor, fuse and main meter readings to give related comments or remarks.

This resulted in identifying 'permanent loads' which are not connected via socket or sensor. For these loads, electrical parameters are not sent from a sensor for identification. The permanent loads which are directly connected to the power supply line are usually with higher consumption when compared to plug-in devices. Since sensors are not installed on permanent loads, the appliances can be further identified (classified) by estimating a device with its energy consumption and using extra parameters (e.g. hour of the day, season, temperature) as required.

To estimate these permanent appliances, the previous consumption profile of various devices from the measurement results is used. Thus from the data gathered at the measurement phase, a range of real power consumption can be developed. As a basic structure, each permanent appliance will have maximum and average real power consumption values in the library. Then once it is confirmed from the balance sheet calculation that there exists a permanent load, the next step would be to record the calculated value of the real power consumption of the permanent load. This consumption value will be crosschecked with the values in the library. For some permanent loads, considering external factors will aid in accurately estimating the appliance; For instance temperature reading would be inversely related with direct electric heating system consumption. It is eventually possible to estimate the name of the permanent load corresponding with the previously known consumption value and the external parameters. Other than temperature, Season and time of operation can also be considered as external factors. (Fig. 5)

On the other hand, devices monitored by sensors are to be identified by the finger print identification process. Sensors send power and energy messages with parameters, (i.e. P, F.P.F, T.P.F, THD, C.F, 3rd, 5^{th} and 7^{th} harmonics), used for device fingerprinting. The algorithm for device fingerprinting will process the data to name the appliance. These names, with corresponding energy consumption readings of the sensors, are then provided to the balance sheet to process and display consumption shares of devices connected through sockets. Hence, for plugged in devices with sensors, the balance sheet presents additional information of consumption shares and cost shares of the appliances.

At this phase the balance sheet assumes that it gets identified-device data from the fingerprinting process. Thus it uses a model of incoming data with distinct consumption values for each appliance code. Percentage consumption of the devices is then displayed on a pie-chart.

The balance sheet can also be applied for indirect detection of sensors and fuse-meters. Important application of the detection is tracing defective sensors and fuse meters to generate alerts. This is confirmed when installed fuse-meters or sensors are not displayed to have valid measurements. For instance, when the main meter reading is less than the sum of the lower level energy meters, the estimated alert can be ‘Defective main meter’.

On the actual test sites, not all fuse meters in a household were installed on the fuse lines. Hence, if applied in the balance sheet, this would provide incomplete information and the balance sheet will always display the remark ‘There are unmeasured fuses’. Similarly unless all the socket points in a household are installed with sensors, the balance sheet will always assume that there are permanent loads connected in the household.

Most importantly, when the fingerprint identification algorithm is fully ready for application, the balance sheet will use the actual results for device level consumption information. It is so far assumed that the algorithm will eventually identify a few model appliances. Thus at this stage appliance-codes of devices and their hourly consumption are important attributes considered in the model database. For the balance sheet, the related table used in the developed ‘beaware’ database is device_energy.

<u>Columns in the 'device_energy' table:</u>

App_code - lists the codes given to different electrical household appliances.

App_type - provides the corresponding names of appliances for the appliance codes.

Consumption- Electrical Energy consumption readings for each device
Date and **Time**

Until the device fingerprinting fully provides device level information, the balance sheet model had to use the server data. But this will not allow it to update the information when a device plugged into a sensor is changed. This is because the server data will not be affected by the change. In the long term, the balance sheet has to entirely use the device fingerprinting results. By means of these device fingerprinting results, it provides reliable and updated device information.

To sum up, there are three broad existing categories for the balance sheet to consider. Larger loads connected directly to the electric supply (permanent loads):

These loads include heat pumps, air conditioners and other residential significant loads. The calculated permanent-load consumption and external indicators (E.g. temperature, season, and time) will be used for estimating the devices.

i) Plugged in devices with device fingerprinting results:
The outputs of the processed algorithm for device fingerprinting will be used. Then consumption share of the devices is calculated and displayed.

ii) Plugged in devices without device fingerprinting results:
Previously known device identity and consumption data from the server are to be used for identification.

4.2 Displaying Consumption shares

To simulate the balance sheet information for consumption shares, a pie-chart is used on the web page. Here the consumption difference between distinct household appliances can be observed simply on the pie chart. A customer provides the input for the current tariff and the required consumption profile is displayed accordingly.

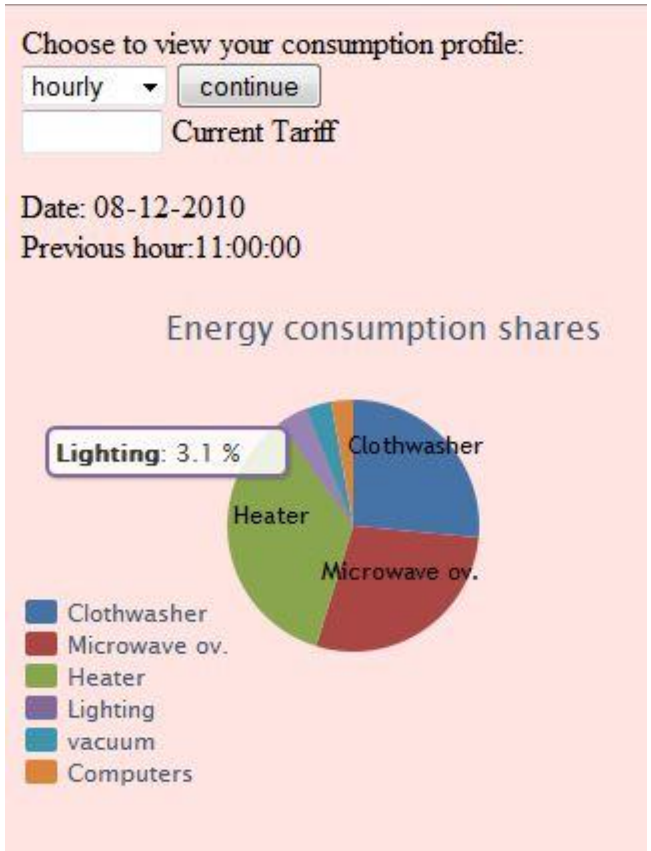


Fig.4 Sample calculated consumption shares of appliances on the model balance sheet

The consumption share will display shares of permanent as well as temporary (plugged in) devices. Since the sensor is not installed at the main meter level, permanent loads are estimated only by their calculated consumption information. For a better accuracy, external factors such as temperature were to be additionally considered. To confirm the implication of these factors (e.g. temperature), test samples should be taken and then studied from consumption data and corresponding temperature data. The brief analysis of the samples will give the relationship between the consumption of the permanent load with temperature. For instance as discussed earlier, direct electrical heating systems (e.g. ground source heat pumps) are expected to consume electricity with inverse relation to temperature readings. The results of the analysis will be inputs for a more accurate design for estimation (Fig. 6). The Load type estimation was tested on the Balance Sheet being displayed as supplementary information included in the table which updates sensor-status (APP –II).

The proposed external factors time of the day, season and temperature are essential parameters to consider in implementing a probabilistic approach to estimate significant load types. However, experimental study results are required on each parameter to confirm the relation with electrical consumption. A sample survey data was taken from a household to assess the general consumption trend of permanent loads with respect to outdoor temperature (Fig.5 and App I). Results implied that, the temperature data as well as the other proposed external parameters (i.e. Season and Time of the day) need to be analyzed thoroughly in the future with electrical consumption data of several significant loads.

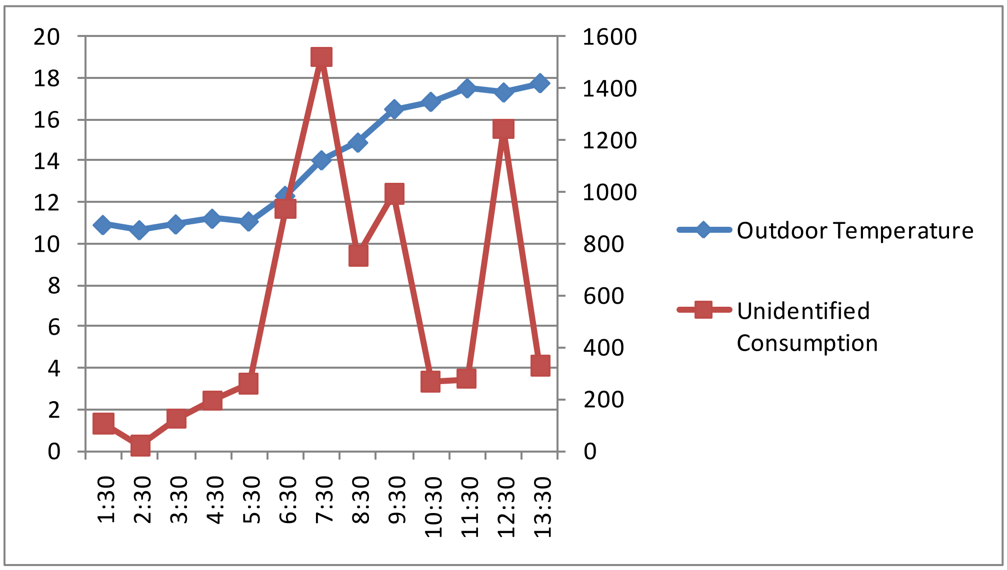


Fig.5 Outdoor temperature and energy consumption of directly connected loads

Even if the applicability of the parameters is not verified yet using probabilistic approach, practical assumptions were considered for the model balance sheet so as to simulate the load identification. For instance, temperature reading is expected to have inverse relationship with direct electrical heating system consumption. Air conditioners are likely to operate during the summer season and there is a common time of the day for certain residential appliances to be used.

Considering plugged in devices installed with sensors, it uses data from the table device_energy. Here in this table are listed different devices with energy consumption values and corresponding date and time stamps. The variables can be replaced with the online actual outputs of the processed algorithm for device fingerprinting (when it is fully implemented). First, all the data contained in the table is extracted. Then data of current date and previous hour is selected. Consumption readings of different appliances at this hour are summed up to give total energy. By detecting the appliance codes related with each row of this data, shares of each device are then recorded. The percentage shares are finally calculated from the individual shares and the summed total energy consumption. These percentages are given as inputs to the dynamic pie chart which displays graphically the consumption shares (Fig.4).

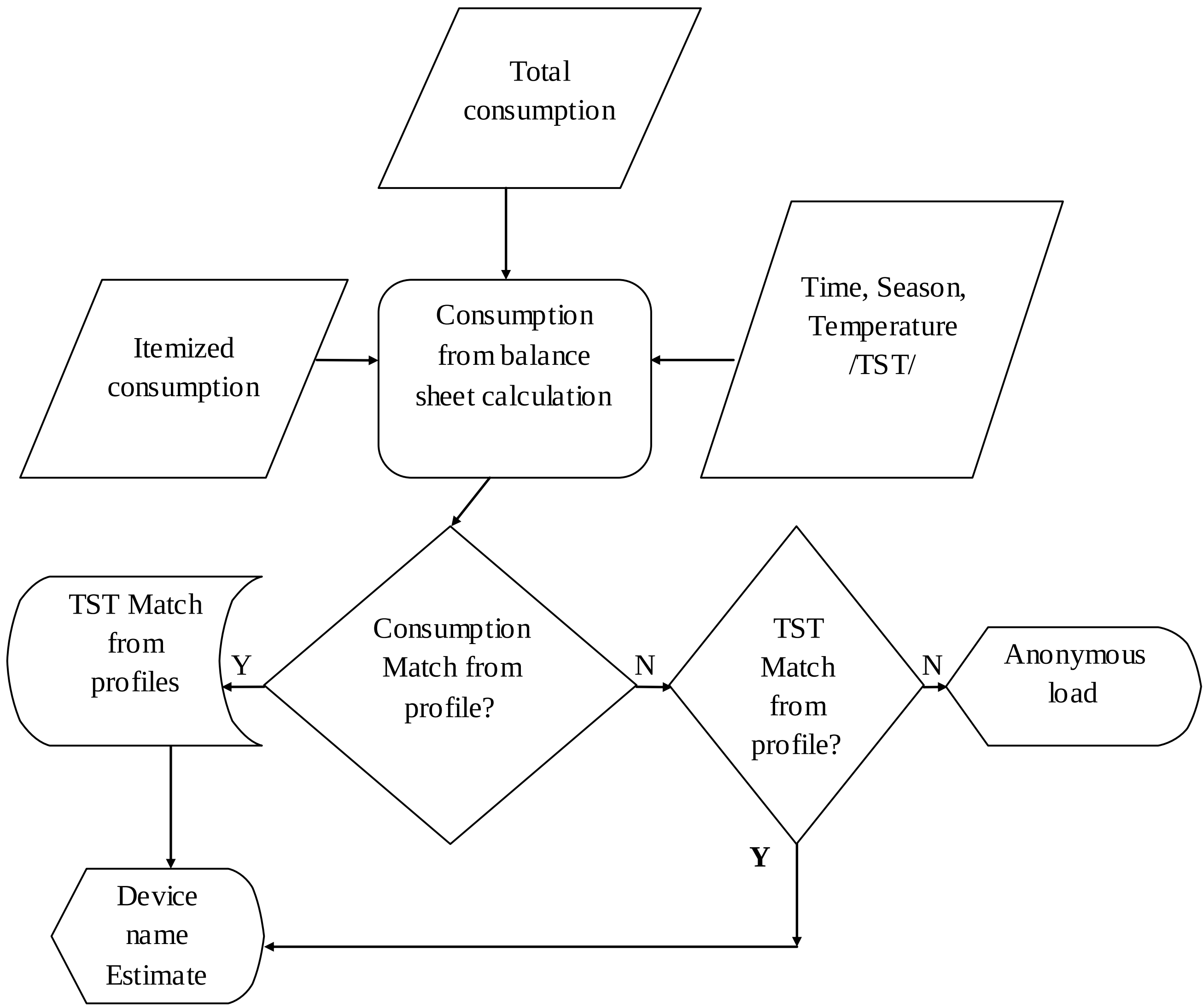


Fig. 6 Estimating permanent load types - basic structure

*Itemized consumption data is in the future to be totally obtained from the outcome of device fingerprinting

*TST data represents time of the day, the typical season of the year and the range of temperature for the unidentified load to operate.

*The offline range for consumption values with corresponding device-names will have additional alternatives of load combinations (load models) for directly-connected devices operating at the same time.

The following steps are implemented on the model balance sheet to display consumption shares on the pie chart as shown in Fig.4.

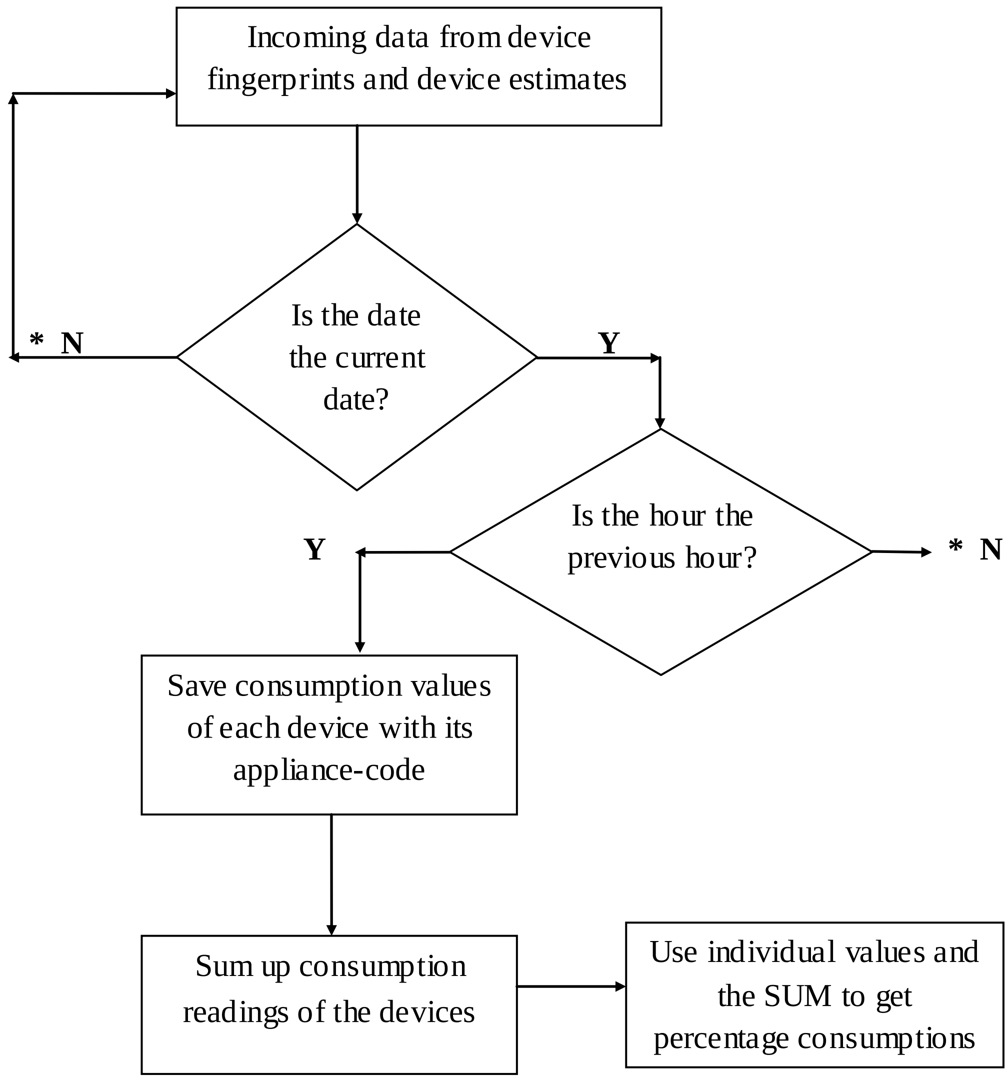


Fig.7 Steps for Consumption-Shares in the previous hour

4.3 External parameters for load type estimation

The need for load type estimation was due to the unidentified portion of energy consumption by electrical devices which are not monitored by sensors. As described earlier the external parameters proposed here are Temperature reading, Season of the year and Time of the day for which the device is in operation. On most of the other studies direct electric heating consumption is mentioned to be characterized by a clear inverse relationship with outdoor temperature. However, further studies, data and data analysis are required to evaluate operational behavior of other heating systems with temperature. While considering the season parameter, the balance sheet can at least start with the two major seasons, i.e. summer and winter. Typical appliances likely to operate in summer include air conditioner and table fan.

On the other hand, previous studies have statistically analyzed at which hour of the day an appliance is more likely to operate. This was presented as hourly probability factors of electrical appliances within 24 hours period [27] [App. V]. The above analysis and implementation of the other external parameters leads to a probabilistic approach to estimate the name of a device taking non-electrical external parameters as inputs.

Moreover load-models have to be considered in the offline data within the library or the database. This is because of the fact that directly connected loads have the probability to operate simultaneously. In this case the consumption range would be different from the individual profile for appliances. Thus for a more advanced load type estimation, expected load type combinations with corresponding consumption ranges need to be considered in the load type estimation.

Sample load type estimates by the balance sheet using the parameters consumption, temperature and season are given in App. II. Here in addition to records of their rated consumption, a range of temperature values was saved in the library for each permanent load. The unlikely operating season for some devices was also recorded in the database (e.g for space heater the unlikely season was summer). The load type estimation used these parameters for the sample estimates whenever the remark from the calculations reports that a permanent load is encountered.

4.4 Calculating cost

Depending on the user's choice, the balance sheet model displays daily consumption costs and cost of the previous week. Besides that, it always updates and displays itemized consumption cost of the previous hour for appliances within the household.

4.4.1 Total cost

The user is required to choose between hourly and daily consumption. For the hourly choice, hourly information is displayed for every hour of the current date.

For the daily choice, the information is from the previous 7 days; providing the recent week's information.

Case a) when user choice is hourly, the cost information should be of today's hourly consumption and cost.

Programming and calculation steps to determine today's cost:-

1. Fetch all data from hourly_energy table
2. Extract the hourly_energy attribute
3. When the corresponding date is checked to be today (the current date), sum up the energy values of each hour within the 24 hours. Assign the sum to a variable named 'total energy'.
4. Multiply this total energy consumption with the current tariff and assign the result to 'today's cost'.
5. Finally display the current tariff, today's cost and total energy consumption at this current date.

Case b) When user choice is daily, the calculation considers the previous 7 days and the reported cost will be of the recent week's consumption cost.

Steps followed to write the programming code for Weekly cost (This week's cost)

1. Fetch all the data from daily_data table
2. Extract the date and average_energy attributes
3. For each of the last 7 days (excluding the current date),check if the extracted date value has a match
4. When a match is found record the corresponding energy values
5. Sum up these values to find the total energy of the week

6. Multiply this sum with the current tariff to find the weekly cost
7. Display the current tariff, the total weekly energy and the total weekly cost

For all cases (either of the hourly or daily user choices) the balance sheet goes through the following steps:

i) Checks if the given recent tariff value is greater than zero
ii) If it is greater than zero, multiplies it with total energy to find total consumption cost
iii) If it is less than or equal to zero, displays total energy and asks the user to insert recent tariff* value.
iv) For tariff greater than zero, it displays recent tariff, total energy and total cost.

*If the user is unaware of the current tariff, he/she will be advised to follow the link labeled as 'recent tariff' on the balance sheet. This link leads the user to recent information which lists consumption costs for different areas.

Once the device consumption is known as illustrated in section 1, the consumption cost information is taken further. Consumption cost, related with each appliance, can be presented with the pie chart which provides consumption shares.

4.4.2 Cost shared by appliances

The consumption share of the permanent as well as the plugged in devices is determined as illustrated in section 4.3.1. For the simulated pie chart, since the consumption share is calculated and displayed, the next task was to calculate the shared cost. The electrical consumption cost is calculated for each category of appliance. The data is taken again from the device_energy table which is assumed to record the outputs of the processed algorithm for device fingerprinting. The written programming code first converts the watt-hour consumption reading into kilo watt hour. Then it multiplies the result with the current tariff which the user provides as an input to the balance sheet. Finally the balance sheet displays each device name with the corresponding consumption cost within the previous hour (Fig. 8).

For estimated load types, however, the balance sheet will exploit the outcomes of load-type estimation. Once the unidentified consumption is calculated and is crosschecked with the external parameters to estimate the load type, the corresponding consumption cost will be displayed along with the appliance type.

Recent tariff ($/kwh) :	0.42
Today's total energy(Wh):	10075
Today's cost ($) :	4.2315
Device	Cost in the previous hour($)
clothwasher	0.315
Microwave	0.336
Heater	0.42

Fig. 8 Sample calculated display: Total cost of recent consumption and cost shared by appliances.

The preceding snapshot displays the total cost of the current day till the recent hour. Then it presents below the cost shared by each device within the last hour. The previous simulated pie chart displayed the consumption share related with this cost during the last hour.

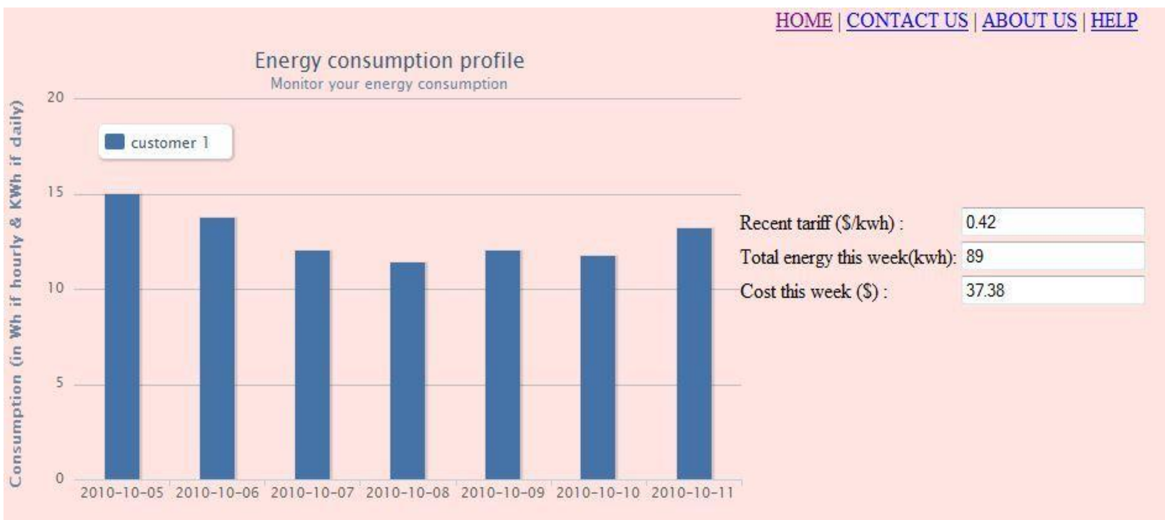
The percentage cost shares are now worked out from the individual electrical consumption costs and the total cost. The total cost here will be calculated by summing up the individual consumption readings at the specified time (e.g. previous hour).The sum will be multiplied by the tariff to give the total cost.

4.4.3 Accuracy of calculations and load type estimation

The proposed feedback presentation system-accuracy will be mainly dependent on the accuracy of the load identification algorithm which provides the input data to the web-based balance sheet. However, since the load identification algorithm is again dependent on the sensor data, the accuracy of the sensor will also indirectly affect the accuracy of feedback calculations. Similarly, even if it cannot be quantized in percentages before analyzing an extensive practical survey data on load type estimation, the use of external parameters for load type estimation is an additional source of inaccuracy.

The load identification algorithm being developed on the other branch of this study is not fully completed and practically implemented yet. Thus the accuracy of the feedback system is not surveyed and statistically calculated to be presented at this stage. But on the basis of the progress reports, it is stated that the identification algorithm has the classification potential of an initial overall accuracy value of 62.3%. In addition much higher accuracy values are expected with more records in the library and in the case of mass deployment. Thus the accuracy of the feedback information to be presented can be estimated roughly to be above 60 %.

Fig. 9 Snapshots of Daily and Hourly consumption feedback samples respectively.



5. CONCLUSION

From the two major feedback presentation methods (i.e. Comparative and historical), earlier studies with survey data confirmed that historical feedback is more effective than comparative feedback. In this study, the proposed web based feedback presentation method is established on the need for an effective and timely presentation technique. Thus the information provided by the Balance Sheet (which displays the feedback to the customer) is made to present historical electrical consumption profile of the entire household and certain appliances within the household.

Since public service is shifting totally towards the use of globally available internet applications, the proposed web-based feedback presentation method is very likely to be effective and to be preferred by the customer. The balance sheet calculates and displays recent consumption profile and cost values of an entire household according to a user’s request. It additionally provides the recent operational states of individual appliances and their consumption shares with respect to the total consumption. Hence, a customer will be able to monitor the total consumption by observing the recent and aggregate consumption behavior. It will, as well, be possible to detect and monitor individual electrical appliances within a household to achieve the optimum consumption behavior with reduced consumption cost.

The potential of load disaggregation for feedback presentation was assessed to be high. However, it is recommended that further studies and survey should be conducted on external factors used to estimate load types of appliances which are not monitored directly by plug-in sensors. On the other hand, standby consumption of the electrical devices was not considered in the entire study. This was due to the initial observation results which proved the standby consumption to be negligible for most of the selected residential appliances. However the aggregate standby consumption impact should be assessed which implies that a survey and study on the standby consumption behavior of appliances is essential to be considered in the future.

During the research study, it is suggested that combining the balance sheet approach and device fingerprinting is a better alternative for mass deployment. The suggestion was given due to the high cost which will be required at this progress level if monitoring sensors are installed for every device in a household. To sum up, the web-based Balance Sheet is a convenient and an effective way of feedback presentation and load monitoring. Subsequent to certain updates and a few enhancements, it can be employed in the public service and is very likely to win the consumer preference.

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APPENDIX –I Survey consumption data with temperature

Date	Time	Temperature (◦C)	Permanent load consumption*	Total	Fridge	Laptop Chargers	Microwave	Tea Kettle	Washing Machine
6/18/2010	0:30	10.8	-	NaN	163.15	2.1	0	-0.03	-0.04
6/18/2010	1:30	10.93	103.31	112.4	7.06	2.1	0	-0.03	-0.04
6/18/2010	2:30	10.68	20.37	129.3	106.9	2.1	0	-0.03	-0.04
6/18/2010	3:30	10.96	123.34	133.24	7.87	2.1	0	-0.03	-0.04
6/18/2010	4:30	11.23	195.02	299.2	102.15	2.1	0	-0.03	-0.04
6/18/2010	5:30	11.1	259.33	422.5	56.24	2.1	104.9	-0.03	-0.04
6/18/2010	6:30	12.33	932.07	996.3	62.2	2.1	0	-0.03	-0.04
6/18/2010	7:30	14.04	1522.29	1607.4	83.08	2.1	0	-0.03	-0.04
6/18/2010	8:30	14.89	753.47	837.1	42.5	2.1	39.1	-0.03	-0.04
6/18/2010	9:30	16.5	992.99	1082.5	87.48	2.1	0	-0.03	-0.04
6/18/2010	10:30	16.85	265.87	325.6	57.7	2.1	0	-0.03	-0.04
6/18/2010	11:30	17.5	277.87	350.3	69.9	2.6	0	-0.03	-0.04
6/18/2010	12:30	17.3	1242.39	1287.9	43.15	2.43	0	-0.03	-0.04
6/18/2010	13:30	17.75	328.94	445.6	103.7	2.1	10.93	-0.03	-0.04
6/18/2010	14:30	17.93	-	NaN	89.7	NaN	0	-0.03	NaN
6/18/2010	15:30	17.68	-	NaN	NaN	NaN	NaN	NaN	NaN

PERMANENT LOADS IN THE HOUSEHOLD	Note that Permanent load consumption is assumed to be the arithmetic difference between the total load and sum of the individual loads.
Electrical heating (6 separate heaters)---- 350 W and 250 W	
Sauna stove ----------- --- 6 KW	
Floor heating in shower area -------------- Unknown	
Water heater --------------- 1KW	
Oven/stove --------------- Unknown	
Dish washing machine --------------- Unknown	
Lamps (mostly 1st gen energy saving models)	

APPENDIX –II Load type estimates

Table5.

Estimated load types which are not monitored by the plug-in sensors. The load type estimation was simulated by using the proposed external parameters (i.e. Temperature, Season) and it displays the load type whenever a permanent load is connected.

Fuse Meters and Sensors

Time	Fuse 1 measured(Wh)	Sensor 1(Wh)	Sensor 2(wh)	Remark
00:00:00	12	5	7	All loads connected with sockets
01:00:00	16.4	10.2	6.2	All loads connected with sockets
02:00:00	30	10	5	permanent loads connected to fuse
Estimated load type	Lighting			
03:00:00	18	11	7	All loads connected with sockets
04:00:00	4530	5	0	permanent loads connected to fuse
Estimated load type	Water Heater (40g)			
05:00:00	12	7	5	All loads connected with sockets
06:00:00	57	5.4	1.6	permanent loads connected to fuse
Estimated load type	Lighting			
07:00:00	600	26	14	permanent loads connected to fuse
Estimated load type	Air conditner			

APPENDIX –III

Table 6. Fuse meters' status from Main meter readings.

Main meter and Fuse meters

Time	Main meter(Wh)	Fuse 1(Wh)	Fuse 2(Wh)	Remark
00:00:00	380	12	325	There are unmeasured fuses
01:00:00	260	16.4	243.6	All fuses are measured
02:00:00	240	30	205	There are unmeasured fuses
03:00:00	3020	18	14	There are unmeasured fuses
04:00:00	4636	4530	106	All fuses are measured
05:00:00	289	12	10	There are unmeasured fuses
06:00:00	300	57	15	There are unmeasured fuses
07:00:00	950	600	250	There are unmeasured fuses

APPENDIX - IV

Table 7. Appliance list and number of samples that were used in the measurement work for survey data.

	Appliance name	No. of samples
1	Desktop PC (processor)	4
2	CRT PC monitor	2
3	LCD PC monitor	2
4	Laptop	3
5	Printer	1
6	Scanner	1
7	Energy-saving/CFL lamp	4
8	Fluorescent lamp with conventional ballast	4
9	Fluorescent lamp with electronic ballast	2
10	LED lamp	4
11	Incandescent lamp	2
12	Halogen lamp	2
13	Microwave oven	2
14	Electric cooking plate (*)	**1**
15	Toaster	1
16	Freezer	1
17	Dishwasher	2
18	Water heater (**)	-
19	Sauna stove (**)	-
20	Refrigerator	1
21	Coffee maker	2
22	Hi-Fi DVD/CD player (*)	**1**
23	CRT television	2
24	LCD television	2
25	Plasma television	1
26	Electric space heater	2
27	Central air conditioner (**)	-
28	Table fan	2
29	Cloth dryer (**)	-
30	Washing machine	1
31	Vacuum cleaner	2
32	Air source heat pump (**)	-
33	Ground source heat pump (**)	-

(*) – Planned to be measured (**) - Not measured due to lack of samples or inaccessibility of socket points

APPENDIX - V

BASIC PROGRAMMING CODES

Below are given some of the basic programming codes written to develop the model balance sheet.

1. Codes to display Hourly consumption

```
<form action="preview.php" method="post">

Choose to view your consumption profile:

</br><select name="selectedtime">

<option>hourly</option>

<option>daily</option>

<option>monthly</option>

</select>

<input type="submit" value="continue"/>

-----------------PHP CODE----------------

switch ($selectedtime){

        case "hourly":  //************FIRST CASE HOURLY PROFILE

                while ($field = mysql_fetch_array($res))

{  if ($now==$field['date'])

{

$time[$i] = $field['time'];

$energy[$i] = $field['main_meter'];
```

APPENDIX - V

```
$i+=1;
}                }
$c=0;$totalenergy=0;
$sql = "SELECT * FROM energy_meters";
$res = mysql_query($sql);
        while ($field = mysql_fetch_array($res))
                                        {
$costenergy[$c]=$field['main_meter'];
if ($now==$field['date'])
{ $totalenergy+=$costenergy[$c];}
$c=$c+1;    }
#*************** 2. Adding the JavaScript into PHP to initialize the chart on document ready
            echo "<script>;
              $(document).ready(function() {
                 var chart = new Highcharts.Chart({
                       chart: {renderTo: 'container',
                             defaultSeriesType: 'column' },
                       title: { text: 'Energy consumption profile' },
                       subtitle: { text: 'Monitor your energy consumption' },
```

APPENDIX - V

```
xAxis: { categories: [
'$time[0]', '$time[1]', '$time[2]', '$time[3]', '$time[4]', '$time[5]', '$time[6]',
'$time[7]', '$time[8]', '$time[9]', '$time[10]', '$time[11]','$time[12]',
'$time[13]', '$time[14]', '$time[15]', '$time[16]', '$time[17]', '$time[18]',
'$time[19]', '$time[20]', '$time[21]','$time[22]', '$time[23]',
] },
yAxis: { min: 0,
title: { text: 'Power (W)' }
},
legend: { layout: 'vertical', backgroundColor: '#FFFFFF',
style: { left: '100px', top: '70px',
bottom: 'auto'
} },
tooltip: { formatter: function() {
return '<b>'+ this.series.name +'</b><br/>'+
this.x +', '+ this.y +' Wh'; } },
plotOptions: { column: { pointPadding:
0.2, borderWidth: 0 } },
series: [{name: 'customer 1',data: [$energy[0], $energy[1] ,$energy[2],
$energy[3], $energy[4], $energy[5],$energy[6], $energy[7],$energy[8],
$energy[9],$energy[10], $energy[11] ,$energy[12],
$energy[13],$energy[14], $energy[15],$energy[16],
$energy[17],$energy[18], $energy[19], $energy[20], $energy[21]
,$energy[22], $energy[23] ]
}] }); });
```

APPENDIX - V

2. **Codes to display Daily consumption and calculate recent weeks consumption**

```
#second case ,daily profile
case"daily":
 echo "<br/>Daily profile";

 $i=0;$totalenergy=0;

 $sql = "SELECT * FROM daily_data";

 $dailyres = mysql_query($sql);

          while ($field = mysql_fetch_array($dailyres))   //this is for
the bar chart

{        $alltime[$i] = $field['date'];

$allenergy[$i] = $field['average_energy']; $i+=1;}

 $j=6;//This is to reverse the graph and see the current date at the right end

for ( $c=1;$c<8;$c+=1)  //This is for adding the values for the last 7 days

{ $yesterday = mktime(0, 0, 0, date("m"), date("d")-$c, date("y"));

echo "</br>";   $pastday[$c]= date("Y-m-d", $yesterday);

for($k=0;$k<$i;$k+=1){ echo "</br>";

 if ($pastday[$c]==$alltime[$k])

{$time[$j] = $alltime[$k]; //the first match with the current date,
pastday[0],                         at the right end of  the graph

$energy[$j]    =$allenergy[$k];

  $totalenergy+=$energy[$j];}

  } $j-=1; }
```

APPENDIX - V

3. Codes to process data and display Fuse-meter status within a table

```
echo "<div id='table1' style='

 top: 450;    left:0; position: absolute;   z-index: 1;padding: 15; visibility: show;'>";

echo "<b>Main meter and Fuse meters</b><br/><br/>";

echo "<table border=\"1\" >";

echo "<tr><th>Time</th>";

echo "<th>Main meter(Wh)</th>";

echo "<th>Fuse 1(Wh)</th>";

echo "<th>Fuse 2(Wh)</th>";

echo "<th>Remark</th></tr>";

$i=0; $sql = "SELECT * FROM energy_meters";

  $meterres = mysql_query($sql); while ($field = mysql_fetch_array($meterres))

{if ($now==$field['date']) { $time[$i] = $field['time'];

$main[$i] = $field['main_meter']; $fuse1[$i] = $field['fuse_meter1'];

$fuse2[$i] = $field['fuse_meter2']; $fusesum=($fuse1[$i]+$fuse2[$i]);

if ($fusesum==$main[$i]) { $remark[$i]="All fuses are measured";}

elseif ($fusesum < $main) {$remark[$i]="There are unmeasured fuses"; }

echo "<tr><td>";//********************** Table 1 frame starts here

        echo $time[$i]; echo "</td><td>"; echo $main[$i];

        echo "</td><td>"; echo $fuse1[$i];
```

APPENDIX - V

```
echo "</td><td>"; echo $fuse2[$i];

echo "</td><td>"; echo $remark[$i];

echo "</td></tr>"; $i+=1;}     } echo "</table>";

echo "</div>";

#**************** The second table goes here **********
*************** *******

 echo" <div id='table2' style='

   top: 450; right:0;width:700; position: absolute;

   z-index: 1;padding:15; visibility: show;'>";

echo " <b>Fuse Meters and Sensors</b><br/><br/>";

echo "<table border=\"1\" >";

echo "<tr><th>Time</th>";

echo "<th>Fuse 1 measured(Wh)</th>";    //measured and received fuse 1
energy value at base station

//echo "<th>Fuse 1 summed(Wh)</th>";   //summed energy values of
sensors to give fuse 1 energy

echo "<th>Sensor 1(Wh)</th>";

echo "<th>Sensor 2(wh)</th>";

echo "<th>Remark</th></tr>";

$sql="SELECT * FROM sockets LEFT OUTER JOIN socketfuse_info on
sockets.sensor_id = socketfuse_info.sensor_id WHERE
socketfuse_info.fuse_no= 1 "; /*considering data from the two tables
(sockets and socket fuse info) having s.ids connected with  fuse 1*/
```

APPENDIX - V

```
$res = mysql_query($sql);$k=0;

while ($field = mysql_fetch_array($res))

{ if ($now==$field['date']){

        $time[$k]= $field['time']; $sensorenergy[$k]=$field['energy'];

        $k+=1;}

}

$normtime=array(0=>"00:00:00",1=>"01:00:00",2=>"02:00:00",3=>"03:0
0:00",4=>"04:00:00",5=>"05:00:00",6=>"06:00:00",7=>"07:00:00",8=>"0
8:00:00",9=>"09:00:00",10=>"10:00:00",11=>"11:00:00",12=>"12:00:00"
,13=>"13:00:00",14=>"14:00:00",15=>"15:00:00",16=>"16:00:00",17=>"
17:00:00",18=>"18:00:00",19=>"19:00:00",20=>"20:00:00",21=>"21:00:
00",22=>"22:00:00",23=>"23:00:00");

if($k>0){   //checking if there is any data of the current date

for ($i=0;$i<24;$i+=1){    $fuse1energy[$i]=0;  //considering all 24 hrs in
a day

for ($j=0;$j<$k;$j+=1) {               //checking all data rows available

if ($normtime[$i]==$time[$j])  {      //for individual time stamps matching
them with the existing normal time array, to sum up values of same time
stamp
        $fuse1energy[$i]=($fuse1energy[$i]+$sensorenergy[$j]);

                                        }}

                                if ($fuse1energy[$i]!=0){

                                        echo "<tr><td>";echo $normtime[$i];

                                        echo "</td><td>";
```

APPENDIX - V

```
$sql = "SELECT * FROM energy_meters";

$meterres = mysql_query($sql);$count=0;

while($field = mysql_fetch_array($meterres))

{if (($field['date']==$now) &&

($field['time']== $normtime[$i] ) ) {echo$fuse1read[$count] = $field['fuse_meter1']; //measured value of fuse 1 from the table 'energy meters' } }

echo "</td><td>";

if ($fuse1[$i]>$fuse1energy[$i]) //when the reading from measurement exceeds the summed up value, permanent loads or unmeasured socket points exist

{$permanent=$fuse1[$i]-
$fuse1energy[$i];

$remark[$i]="permanent loads
connected to fuse";}

elseif($fuse1[$i]=$fuse1energy[$i]){$remark[$i]="All loads connected with sockets $permanent=0;}//otherwise the sum of the energy values from the sockets is equal to the reading

for ($j=0;$j<$k;$j+=1) { if ($normtime[$i]==$time[$j]){echo $sensorenergy[$j];echo "</td><td>";}} //for all rows having values for

//the time being considered (normal time)

echo "$remark[$i]"; echo "</td></tr>";

//***ESTIMATING LOAD TYPES IN THE SAME TABLE**************************
```

APPENDIX - V

```
$temperature=27;$season=summer;//This is for trial,but it should identify
the temp from          //incoming data and season from the current date and
month

                    $sql = "SELECT * FROM appliance_info";

                    $range = mysql_query($sql);

while (($field = mysql_fetch_array($range))&&($permanent!=0))

                { if        (($permanent<=$field['wattMax'])          &&
($permanent>=$field['wattAvg']))

                      {echo "<tr><td>";

 if(($temperature>=$field['tempMin'])&&
($temperature<=$field['tempMax']))

{if ($season!=$field['NOTseason']) //Find and avoid the unexpected
season for the device to //operate,e.g space heater is not expected in
summer                    { echo "<font color='red'>Estimated load
type</font></td><td>";

               echo $loadname=$field['app_name'];echo "</td><td>";}}

                       elseif($field['NOTseason']=='any')

             {echo "<font color='red'>Estimated load type</font></td><td>";

                       echo $loadname=$field['app_name'];echo "</td><td>";}

                       }   }//END OF ESTIMATING LOAD TYPE }
echo "</td></tr>";

                                    } }

echo "</table>"; //echo $permanent=$fuse1[$i]-$fuse1energy[$i];

echo "</div>";
```

APPENDIX - V

4. Codes to calculate and display consumption shares within the pie chart

```
//************starting the pie chart to show consumption shares with the
aid of JavaScript****

$(document).ready(function() {

var chart = new Highcharts.Chart({

chart: { renderTo: 'container2',

margin: [50, 200, 60, 170] },

title: { text: 'Energy consumption shares' },
plotArea: {

shadow: null, borderWidth: null,
backgroundColor: null },

tooltip: { formatter: function() {

return '<b>'+ this.point.name +'</b>: '+
this.y +' %'; }

}, plotOptions: { pie: { dataLabels: {

enabled: true, formatter: function() {

if (this.y > 5) return this.point.name; },

color: 'black', style: {font: '12px Trebuchet MS,
Verdana, sans-serif'

} } } },

legend: { layout: 'vertical',

style: { left: 'auto', bottom: 'auto',
```

```
right: '320px', top: '150px' }},
series: [{ //series for partitions of the pie chart
type: 'pie', name: 'Consumption share',
data: [{ name: 'Clothwasher', y: $share1, sliced: false },
['Microwave ov.', $share2],{ name: 'Heater', y: $share3, sliced: false },
['Lighting', 3.1], { name: 'vacuum', y: 2.7, sliced: false }, ['Computers', 2.3] ]
}] });
});//end of pie chart
</script>"; //********* End of javascript ****************
```

5. Codes to calculate and display total daily cost and cost shared by appliances

```
$sql = "SELECT * FROM device_energy";
$shared = mysql_query($sql);
while ($field = mysql_fetch_array($shared))
{if (($now==$field['date'])&& ($pasthour==$field['time']))
{switch ($field['app_code']){
case "1": //*******************************FIRST CASE for appliance code 1
$shareone=$field['consumption'];
$share1=(($shareone/$total)*100);echo "<br/>";//how much it costs independently
```

APPENDIX - V

```
        if($tariff>0){$cost1=(($shareone/1000)*$tariff);}
        break;
    case "2":
        $sharetwo=$field['consumption'];
        $share2=(($sharetwo/$total)*100);
        if($tariff>0){$cost2=(($sharetwo/1000)*$tariff);}
        break;
    case "3":
        $sharethree=$field['consumption'];
        $share3=(($sharethree/$total)*100);
        if($tariff>0){$cost3=(($sharethree/1000)*$tariff);}
        break;
    case "4":
        $sharefour=$field['consumption'];
        $share4=(($sharefour/$total)*100);
if($tariff>0){$cost4=(($sharefour/1000)*$tariff);}
        break;
    case "5":
        $sharefive=$field['consumption'];
        $share5=(($sharefive/$total)*100);
        if($tariff>0){$cost5=(($sharefive/1000)*$tariff);}
```

```
                break;

            case "6":

                $sharesix=$field['consumption'];

                $share6=(($sharesix/$total)*100);

                 if($tariff>0){$cost6=(($sharesix/1000)*$tariff);}

                 break; }   }      }

  //M 27,END of consumption and cost share calculation

if($tariff>0){

    $todaycost= ($totalenergy/1000)*$tariff;

echo "</br><div id='profile' style=' top:150; right:30; position: absolute;z-
index: 1;visibility: show;'>

<table><tr><td>Recent tariff ($/kwh) : </td><td><input type='text'
value='$tariff' /input></td></tr>

<tr><td>Today's total energy(Wh):</td><td><input type='text'
value='$totalenergy'/input></td></tr>

<tr><td>Today's cost ($)  :</td><td><input type='text'
value='$todaycost'/input></td></tr><tr>

<td>Device</td><td>Cost (previous hour)</td></tr><tr>

<td>clothwasher</td><td>$cost1</td></tr><tr>

<td>Microwave</td><td>$cost2</td></tr><tr>

<td>Heater</td><td>$cost3</td></tr></table>

</div>";
```

APPENDIX - VI

Table 8.

Hourly probability factors of electrical appliances within 24 hours period as given in [27]

		Hours																							
Appliances		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Stove and oven	we	0.20	0.20	0.40	0.40	1.78	2.59	3.19	3.83	3.70	4.13	4.29	4.15	3.89	4.46	5.79	8.76	10.0	10.3	9.24	8.15	5.82	2.79	1.51	0.36
	wd	0.37	0.05	0.00	0.00	0.00	0.17	1.72	2.65	4.37	5.94	6.97	7.86	7.92	7.15	6.39	5.89	6.78	7.41	7.32	7.23	6.93	4.09	2.30	1.02
Microwave oven and Coffee maker	we	0.20	0.20	0.40	0.40	1.78	2.59	3.19	3.83	3.70	4.13	4.29	4.15	3.89	4.46	5.79	8.76	10.0	10.3	9.24	8.15	5.82	2.79	1.51	0.36
	wd	0.37	0.05	0.00	0.00	0.00	0.17	1.72	2.65	4.37	5.94	6.97	7.86	7.92	7.15	6.39	5.89	6.78	7.41	7.32	7.23	6.93	4.09	2.30	1.02
Refrigerator and Freezers	we	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
	wd	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
Dishwasher	we	1.73	0.96	0.40	0.40	0.40	0.96	1.73	2.93	3.75	4.58	4.68	4.68	4.68	4.68	4.68	6.11	6.83	7.16	7.80	8.60	8.16	7.01	5.05	2.03
	wd	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.70	2.00	4.61	7.02	7.23	7.23	7.34	7.34	7.34	7.43	7.43	7.74	7.74	7.43	6.12	3.91	0.90
Clothes-washer and Tumble dryer	we	1.73	0.96	0.40	0.40	0.40	0.96	1.73	2.93	3.75	4.58	4.68	4.68	4.68	4.68	4.68	6.11	6.83	7.16	7.80	8.60	8.16	7.01	5.05	2.03
	wd	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.70	2.00	4.61	7.02	7.23	7.23	7.34	7.34	7.34	7.43	7.43	7.74	7.74	7.43	6.12	3.91	0.90
Televisions and Video recorder	we	2.40	1.20	0.70	0.60	0.70	1.30	2.10	2.45	3.35	3.20	3.20	3.84	3.84	4.00	4.80	6.39	7.99	7.99	7.99	9.59	7.99	6.39	4.80	3.20
	wd	3.40	1.94	0.87	0.77	0.87	0.97	0.97	1.46	2.43	3.40	3.88	4.85	4.85	5.93	6.13	6.80	6.80	6.80	7.77	8.25	6.80	5.34	4.85	3.88
Radio/player	we	2.40	1.20	0.70	0.60	0.70	1.30	2.10	2.45	3.35	3.20	3.20	3.84	3.84	4.00	4.80	6.39	7.99	7.99	7.99	9.59	7.99	6.39	4.80	3.20
	wd	3.40	1.94	0.87	0.77	0.87	0.97	0.97	1.46	2.43	3.40	3.88	4.85	4.85	5.93	6.13	6.80	6.80	6.80	7.77	8.25	6.80	5.34	4.85	3.88
Personal computer and Printer	we	2.40	1.20	0.70	0.60	0.70	1.30	2.10	2.45	3.35	3.20	3.20	3.84	3.84	4.00	4.80	6.39	7.99	7.99	7.99	9.59	7.99	6.39	4.80	3.20
	wd	3.40	1.94	0.87	0.77	0.87	0.97	0.97	1.46	2.43	3.40	3.88	4.85	4.85	5.93	6.13	6.80	6.80	6.80	7.77	8.25	6.80	5.34	4.85	3.88
Lighting	we	1.03	0.33	0.33	0.83	1.78	2.64	3.56	3.74	3.44	3.04	3.04	3.24	3.94	4.14	4.55	4.96	5.79	6.70	8.21	9.11	9.81	8.50	4.32	2.96
	wd	2.55	1.33	1.23	1.23	1.33	1.53	2.13	4.05	5.07	4.99	4.27	3.82	3.57	4.27	4.97	5.50	6.02	6.69	7.34	7.56	6.64	6.17	4.49	3.22
Other occasional loads	we	1.03	0.83	0.83	0.83	1.03	2.04	3.06	3.24	3.44	3.54	3.64	3.74	3.94	4.14	4.55	4.96	5.79	6.70	7.71	8.51	9.01	8.10	5.67	3.66
	wd	2.55	1.33	1.23	1.23	1.33	1.73	2.13	3.55	4.07	3.99	3.77	3.97	4.07	4.47	4.97	6.00	6.32	6.84	7.34	7.56	6.79	6.67	4.84	3.22

we = weekend day
wd = weekday