Mobile Power Information System

Kristian Lund
IDI, NTNU
Trondheim, Norway
kl1986_34@hotmail.com

John Krogstie
IDI, NTNU
Trondheim, Norway
krogstie@idi.ntnu.no

Abstract: This paper investigates different methods for giving users informative feedback on their electricity consumption. After comparing different methods for giving feedback a method comparing power consumption and temperatures is chosen. The purpose is to let power consumers find out how much changes in temperatures affect their consumption. A prototype mobile application has been developed and tested on the Android platform. The application retrieves temperature values and compares this to the consumption of the users. This gives the users a heating efficiency value that describes the amount of electricity used for heating. This is presented with graphs and corresponding values to the users. The results so far are promising, and future work includes a more large scale evaluation by real users.

Introduction

Electricity is used in every home today. It has become an absolute necessity for the society and it would be hard to imagine living without it. As more and more nations crave more power usage, there is a need to reduce the power consumption in particular in the industrialized countries. A way to do this in addition to using better technical solutions is to have people use electricity more efficiently [10]. Detailed information on the usage of electricity is however something that is not available for the normal users. In Norway for instance, most users currently receive a bill four times a year that gives very little information about how the electricity has been used. A reduction in consumption will result in lower bills for the users and if enough reduction is achieved it could result in fewer power plants being needed in the future. This could result in savings for the society by not having to build new power plants and by reducing the expansion on capacity on the electricity grid. A reduction also reduces the amount of CO^2 produced.
During wintertime in Norway most households use a lot of electricity for heating. Other heating sources exist, but electrical heating is the most common kind of heating and as of 2006 98% of the population had electrical ovens. The average amount of electricity used for heating is between 20 and 30% of the total electrical consumption [5]. An application that can give a measurement of how effective the

heating in a house is could therefore be of high benefit for those that try to reduce their power consumption.

In the next section, we outline our research approach. Then we describe different approaches to gather information on energy usage, and existing solutions for utilizing this information. A prototype system for mobile access to this is described and evaluated on a high-level, before discussing further work on the approach.

Research Approach

During this project we seek to answer two research-questions:

1. How can an application that measures energy consumption help users reduce this?
2. What resources can we extract information from when we develop such applications?

For this project we have chosen a design-science methodology [11]. Design science provides seven guidelines, which we have adhered to in the following way:

- Guideline 1 requires that an artefact is produced during the project. In this project the artefact will be a mobile power information system as described in the 'Application' section.
- Guideline 2 demands that the project should produce a solution that can address relevant business problems. In this case energy consumption and reduction of consumption is a matter that is considered to be very important [10]. The problem is to reduce power consumption and the approach taken in this project is to improve the users' information of their consumption. This is one of several approaches to this problem [10], but is acknowledged to have potential impact [18] when done in the appropriate way.
- Guideline 3 demands that the artefact that is produced should be evaluated with well known and accepted evaluation methods to determine the results of the research. In this project the evaluation will consist of the use of scenarios and requirements that was constructed before the design and implementation of the system and is described in the 'Evaluation' section. Scenario building is a widely accepted way to generate design ideas for new systems and products and to identify the possible users and contexts of use for these systems and products. These will be used when the implementation of the system is completed to evaluate the application in real use. If the application performs the tasks and fulfil the demands that was specified by the scenarios and requirements it will indicate that the application is of appropriate quality.
- Guideline 4 stress the need for the application to be a contribution to the area it was designed for. To be a contribution an artefact should either solve an unsolved problem or it should solve a problem with an existing solution in a more effective way. The application in this project attempts to solve the problem of supporting the reduction of energy consumption of the users by

giving them information about their consumption and heating efficiency on a mobile platform. There exists similar applications [10, 15, 18], but none of these tries to solve exactly this problem by using a smart phone application.

- Guideline 5 informs that rigorous methods should be used. We use standard approaches for early stage evaluation.
- Guideline 6 requires that the design should be considered as a search process. This will inherently become iterative as a search for the optimal solution is often intractable in realistic systems. Effective design will require knowledge about both the application domain and the solution domain [11]. Therefore the process becomes iterative since better design decisions can be made with more knowledge. We foresee that additional iterations in the development of this system will happen in the future.
- Guideline 7 demands that the results are presented effectively to all audiences that have an interest in the result. To present something effectively it should be easy to understand and therefore the results from this project are presented in this paper as well as in a background report.

Approaches to Smart Metering

The common way to measure and report the amount of power consumed through a period of time varies between different countries. In Norway it is most common to read of a meter in the house yourself and report the value to your power company. In the UK the common way has been that someone from the power company comes to the house to check the power meter. In Sweden they measure the consumption by radio communication outside of the customer's house. In recent years a prepay solution where customers buy power credit through prepay cards have gained increasing popularity in some areas [14]. These methods are all very basic in the sense that they measure how much electricity that have been used, but it cannot tell anything about how or when the electricity was used. To give more accurate feedback to both the consumers and the suppliers many suggest a smarter electricity grid and so-called smart meters [4]. The goal in many of these solutions is to get either one way or two way communication between the supplier and the consumer. The difference in prices is considered to be small between these two options [14]. Giving the consumer detailed information on own use will often result in an increased awareness about their power consumption and thereby potentially lead to a decrease in total usage [18]. The exact amount of decrease varies in the different studies, but most of them are in the ranges between 3% and 10%. For instance in a study in Norway carried out in 1997 [18] one tried to investigated the effects of informative billing. They manually made more detailed bills by making a breakdown of how much electricity the different appliances consumed. This caused the consumers to increase their awareness and savings at about 10% where reported. To address the need for a smarter grid including improved measuring of consumption the EU-commission has started to design a common standard for the two way communication system [22]. In Norway NVE(Norges vassdrags- og energidirektorat) had initially planned to require smart meters by 2015 [21], but to implement a system that would most probably be in conflict with the standard that EU are designing would be unwise and they therefore decided to delay the planned date to between 2016 and 2020 [2]. On the other hand, pilots are already underway in more limited areas of the country, e.g. in the Trøndelag area, thus we look upon the possibilities with the current technological infrastructure.

Related Projects

Google PowerMeter [9] is a project started by Google in 2009. It is an energy monitoring tool that displays the user's energy consumption through the user's iGoogle site. This means that the application data is stored on the server side and computation is performed on the server side. The client side provides a view to see the data through an Internet browser. The electricity data is provided by the user's power company that transfer these to Google. This means that a smart meter and cooperation from the power company is necessary to use the PowerMeter application. The application lets you track your total energy consumption in real time and it is possible to compare the consumption to averages for different types of houses. An alternative to the PowerMeter is Footprints made by The Energy Detective (TED) [19]. This is an application that is made by the TED Company that also sells smart meters. The TED system is according to some reviews a bit difficult to install, but the Footprints application arguably gives more detailed information than PowerMeter [7]. TED also cooperates with Google so those that use Footprints can also use PowerMeter. WattVett [22] is a system that compares the energy consumption in a house with the outdoor temperature. It can calculate expected values compared to previous measuring for the house and to normal values for that kind of house. The disadvantage with WattVett is that it does not read energy consumption directly and the users have to type in their consumption. The manual for this application specifically mentions this and suggest that the user does weekly readings although this is not required. In relation to the IBM Smart City initiative [15], there are examples e.g. from Dubuque in the US of large citizens dashboards that show water and electricity consumptions in homes using smart meters and provides guidelines and incentives for residents to optimize their individual energy consumptions. In [18] a similar approach from UK is reported where specialized digital displays in the home is used to provide up to the minute information.

Feedback methods

The purpose of this project is to get experiences with giving feedback to the user that increases the awareness of the power consumption. Several methods where investigated to decide how they could provide the users with more detailed, timely information than what they have today, and these are described briefly below. Every method requires that the power consumption can be measured frequently (at least once per hour). An effective tool to use in providing feedback is a price calculation for the consumed electricity. This is effective since it is easier for people to relate to values in money than the amount of kWh that has been used. Price calculation can be performed independently of the method that is used, but more concrete feedback methods will give a more concrete price calculation.

1. Measuring at All Outlets This method measures the power consumption at all power outlets in the house. This would give the most fine-grained feedback that is possible to obtain since it is possible to determine exactly how much electricity every appliance in the house consumed. The technology to measure the consumption to almost this degree of accuracy exists today and an experiment using this kind of technology has been conducted earlier [15, 18]. By measuring every appliance and the total consumption in the home they obtain a system that can give very fine-grained feedback by telling the consumers exactly which appliance that consumed power and when. The results from [20] were a 9% decrease in consumption and the users also developed better energy-conservation awareness. For example they started to unplug appliances to reduce standby power consumption. The major drawback of a method like this is the price of the system. The article never mentions the price of the system they deployed, but according to [6] it is around $5000 which is a considerable amount of money for a normal household. (In [18] they found that 300 pound sterling to be a limit for what people would like to use on energy monitoring).This makes the feedback so expansive that it is very unlikely that it will be installed in a large part of the private houses even if it is the method that should give most effective information.

2. Measuring Consumption in Circuits By measuring the consumption in the circuits in the fuse box it would be possible to obtain a cheaper variant of the previous method. Many houses have separate circuits for large appliances such as water heater, cooker and washing machine. By measuring the circuits it would be possible to get consumption of the appliances and then the remaining consumption could be categorized as 'miscellaneous consumption'. The advantages of this method are that it is cheaper than measuring at all outlets and thereby people might be willing to pay. If each appliance has its own circuit it will also give concrete feedback for every appliance. The drawbacks of this method are that every house has different electricity circuits. This means that it will be impossible to obtain a solution that will be general and equal for all homes. Instead the users would have to set up the circuits themselves in the system and the system would have to adapt to different kinds of circuits. In houses with old circuit systems it is common to have one circuit per room and this also causes that one has other electricity sinks at the same circuits such as lights, panel heater and kitchen machines.

3. Comparison with Similar Houses To compare the power consumption of similar houses a large database that contains measuring data from many different houses is required. If the data should have any significance a large number of categories that houses can be split into and a large number of houses in each category are required. Without a large number the averages are unlikely to give a good guidance and this might give incorrect feedback to the users. Another issue with the comparison method is privacy. All the data should be anonymous and it should not be possible to determine which house any data comes from. The advantages with the comparison method are that it is a very cheap method to implement compared to the measurement methods. The costs limit themselves to a server-solution on the supplier's side and a way to measure the consumption and transfer it on the client side. The drawbacks of this method are that it can be difficult to get concrete feedback from it. It only measures the consumption of the house and compares it to the averages of similar houses. This means that it can be difficult to receive concrete feedback that makes it possible to identify appliances using unnecessary stand-by power during the night and similar issues. It does however give some indications on external conditions that might affect the total consumption. Another issue is the large amount of variables that affect the consumption. Examples of this is the number of people that live in the house, hours spent by these people in the house each day, outdoor temperatures and alternative heating sources such as heat pumps. This solution is thus almost free for consumers, but there will be some costs for the supplier of the data. It does not give concrete feedback, but it can give indications on external conditions or excessively high power consumption. The large number of variables will introduce some challenges when defining categories to group the houses into.

4. Measurement of the Minimal Consumption. Measurement of the minimal consumption is done by finding the hour during a period of at least 24 hours, with the least amount of electricity consumed. During this hour the occupants are assumed to be asleep or away from the house. The consumption is therefore only from heating, standby-appliances and other passive electricity consumers. By comparing this with minimal consumption for previous periods it is possible to determine if the unnecessary consumption has increased.

5. Comparing Consumption to Temperature. In this method the energy consumption of a house is compared to the outdoor temperature. This can give the users an indication of how effective their heating equipment is when their consumption is compared to normal values for similar houses in similar regions. It can also tell users if they are below or above expected values and thereby give an indication to whether their consumption is increasing or decreasing when the consumption is normalized according to the outdoor temperature. The advantages of this method are that it can give very concrete feedback about heating efficiency. This makes it possible for the users to calculate if it would pay off to get new heating equipment than what they currently have, e.g. switch to the partial usage of heat pumps. The drawbacks of this method are that it requires local outdoor temperatures to be effectively captured and events such as vacation-time might cause disturbance in the calculation of expected values.

The "Measuring at All Outlets" and "Measuring Consumption in Circuits" are very similar and only one of them should be included in a system. The "Measuring Consumption in Circuits" is considered to be better since it will have installation costs that might be affordable for most people. A system that includes this method should have a large amount of adaption possibilities in order to work effectively for most houses. Setting up these adoption possibilities would require much effort and it is difficult to decide if a good enough result could be obtained. Therefore it was decided to not include this method in the system. The comparison, heating efficiency and minimal consumption methods can be useful in combination with any of the other methods. The minimal consumption method is easy to implement and therefore it is included in the system. The comparison method is more complicated to implement. The advantages of the method are that it can be implemented with a very basic structure for categorization. Heating efficiency is probably most effective when used together with comparison since values for heating efficiency is something that people will be unfamiliar with. Comparison will give them average values which they can compare themselves to. Heating efficiency is also something that is of great interest for Norwegian conditions since a large part of the energy consumption is used to provide heating. Therefore heating efficiency is included in the system.

Table 1 below summarizes the approaches

Feedback method	**Cost**	**Timeliness of energy data**	**Precision level**	**Effect (if any reported)**	**Intervention**
1. Measure at all outlet	High	Quick	Very detailed	9%, energy-awareness	High
2. Measure in circuits	Cheaper than 1	Quick	High, but less detailed than 1	Difficult to compare with others	Relatively high, specific for each house
3. Comparison with similar houses	Cheap (if classification data is available)	Slow	Low	Reported to have more effect in certain countries than in others [18]	Need to come up with classification scheme, and classification data, privacy and critical mass issues
4. Measure minimum consumption	Cheap	Slow	Low	Limited	Low
5. Comparing consumption to temperature	Cheap	Medium	Low	Not reported, should be used together with comparison	Low, need to capture temperature data

Table 1: Overview of feedback methods

Application

To implement a system that gives users informative feedback about their electricity consumption some kind of hardware that supports a display is needed. The display should be able to show more than just the total number of kWh used. Three different alternatives were analyzed to discover strengths and weaknesses. An application on a PC (personal computer), a separate display in the house, and a mobile solution. In this project the mobile (smartphone) solution was chosen. The added mobility compared to the other solutions make this solution more attractive since one can have information available everywhere and the drawbacks of limited display size and storage size are considered to be challenges that can be dealt with. An additional bonus of added mobility is that comparison with other users of the application through physical proximity could be added in the future. They could then discuss the differences in their consumption and get more knowledge about how they could reduce their usage. Privacy and sharing of data would however be an important issue. Of practical reasons, Android was chosen as implementation platform of the prototype client. A number of scenarios of use were developed to decide more detailed requirements of the system. Scenarios describe individual users in individual usage situations and are not meant to describe the whole system functionality. The value of scenarios is that they concretise something for the purpose of analysis and communication [3, 16].In these scenarios situations where the users have a need for the functionality provided by the system is described. These scenarios ensure that the functionality in the system has a real world situation where it will be useful. The scenarios also serve as a method for evaluation of the system after the implementation is completed. Below two of the developed scenarios are described including illustrations on the developed application and important screenshots of the application when used to address the needs of the scenarios.

The user wants to check her heating efficiency Mona heard from a friend that the differences from well isolated houses to poorly isolated ones could result in huge differences on the electricity bill. She saw that there was a weather forecast with a lot of cold weather and was curious to find out how energy efficient her house was. She decided to get the PowerInformation application that was recommended to her by the same friend and starts it up to find out how efficient her house is.

1. The user starts the application
2. The user selects the desired period as the period by pushing the corresponding button
3. The user toggles the temperature button to on

Result: The application displays the heating efficiency as a marker on a scale. The users can also compare their consumption with the temperature in the graph that is displayed at the top of the page.

Discussion: The heating efficiency is provided on a scale and it should be easy for the user to identify where they are on the scale. The scale should also contain averages for apartments, row houses and detached houses, but averages were difficult to find and therefore they were not included. Fake average values could be used, but this could have caused more problems than benefits and therefore it was not implemented. If real average values had been added this would give the users a way to compare themselves to users in similar houses.

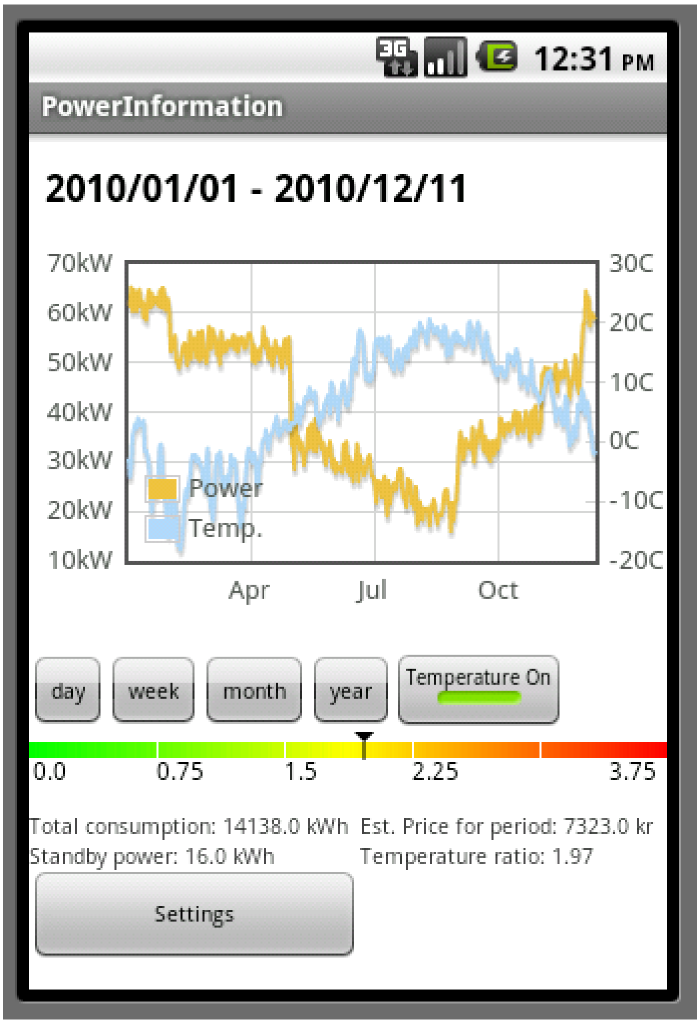

Figure 1 checking the heating efficiency

The user wants to see a detailed summary of the power consumption
Kent has recently acquired the PowerInformation application and after looking around a bit he decides that he could use some more detailed information about his consumption to see his maximum and minimum consumption. He discovers that the minimum consumption is surprisingly high and discovers that the door to the refrigerator is barely open.

1. The user starts the application
2. The user selects the desired period as the period

Result: A detailed list that displays relevant information about the period is displayed at the bottom of the screen.

Discussion: Some details for the power consumption are displayed at the bottom of the screen. The space for these details where small on the screen and therefore few details could be added. They give the users the basic numbers, but interested users might want more. In the scenario the user wanted to see minimum and maximum consumption values for the period. The standby power represents the minimum power consumption in one hour and the max hour consumption is the maximum.

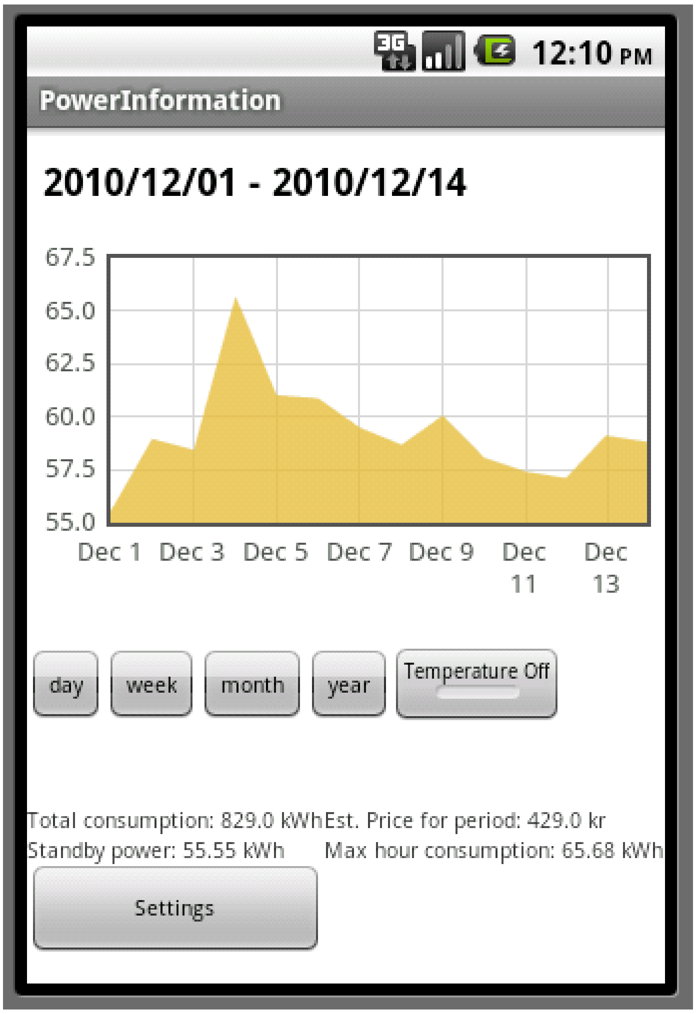

Figure 2 Detailed summary of energy use

Architecture and Implementation

For architecture to be successful it should use well known and effective architectural patterns. In this system the layered architectural pattern was chosen. The layered architecture provides the system with modifiability and portability at the potential cost of performance if data has to be moved through many layers. The below figure illustrates the architecture for the development which will be described further below

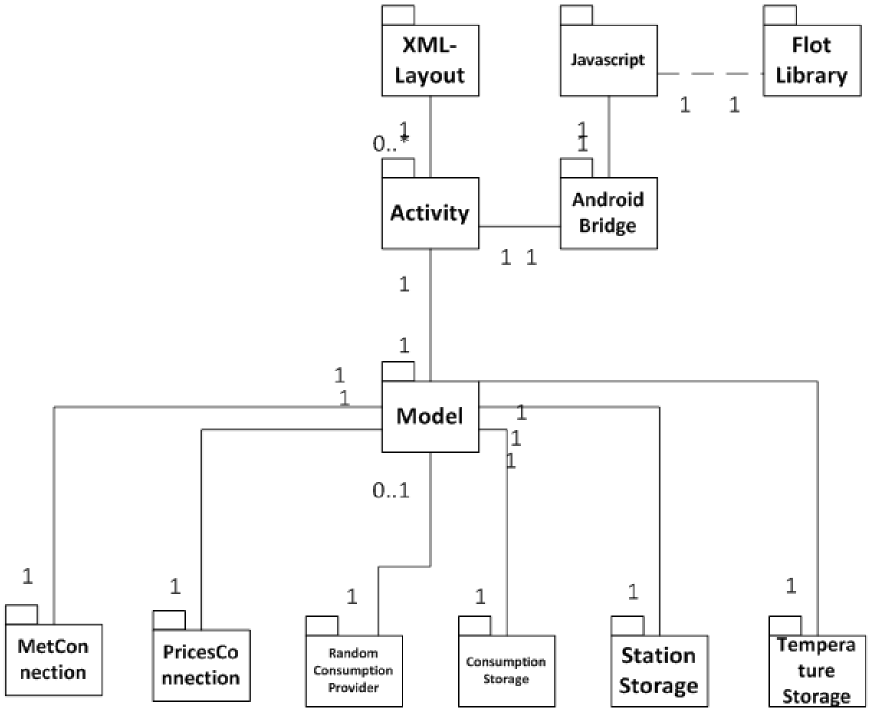

Figure 3 Modules of Power Information System

The application consists of 4 layers.

3. The storage and external resource connection layer (in the bottom of Fig 3): The storage classes create tables in the relational database and offer methods to access these tables from the model layer. The external resource connection classes offer methods to retrieve information from external resources to the model layer.
4. Model layer: The model class holds the data that is represent the system.
5. Controller layer: The activity classes handle input from the users and sends update requests to the model. They also update the layout when the model is changed. The AndroidBridge class is an interface to a JavaScript file. The flot library is an external library (indicated with the dotted line) written in JavaScript and therefore an html-file with javascript is needed to use the methods provided by the library. Flot is a pure Javascript plotting library that produces graphical plots from datasets. Most of the Java graphing libraries that are available are based on Swing and AWT which is not supported on Android.
6. Layout layer: The layout is split between the XML-files and a web-view that is filled by an html file with JavaScript. The JavaScript file uses the flot library to construct a graph from the model data.

The application uses data from two external resources, "konkuransetilsynet" [12] and wsKlima [26]. It connects to both of these through an URL connection. wsKlima offers a WSDL [25] document that will generate a stub that contains methods for connecting to all the web services offered by wsKlima. Unfortunately Android does not support SOAP which is used in the WSDL [23]. An alternative to SOAP on Android is kSoap2 [10]. Several sites indicate some problems with using kSoap2 [13, 23] and that a lot of extra work is required to make it work. Since the wsKlima already offered an URL connection as well the usage of URL was preferred. Using URL creates some extra work per method, but in this project only two methods are used. The data that is retrieved from "konkuransetilsynet" is stored in a text-file. This is handled by a manually created parser. The data that is retrieved from wsKlima is in XML-files. WsKlima is accessed for a station list and average day temperatures for one station.

Evaluation and Conclusion

The application that has been presented should be considered as a prototype. Even so the application serves some important purposes. One of these purposes was to illustrate the technical feasibility of such applications. External resources that could be used such as wsKlima and "konkurransetilsynet" where discovered and technical constraint such as having no support for SOAP on Android was identified. Another purpose is the application itself. The implemented parts of the application and their effects are summarized as following:

- With a prototype, both usability-studies and surveys investigating the expected acceptance of such solutions [8] can be conducted and areas for improvement can be found. The prototype can also be used to test if the hardware in a smartphone can support the application in its current form.
- The system currently supports the power consumption feature and the comparison between temperature and power consumption feature.
- The power consumption feature currently lacks one of the most important parts which are the real power consumption. To gain access to this cooperation with a supplier and access to either their database or information directly from the smart meter is needed. The connection to the consumption data is also something that has been done by several commercial companies [7, 9, 19] and therefore solutions to this problem already exist. We are establishing closer cooperation with local energy-providers to be able to investigate this further in the future.
- The users are able to choose amongst all the weather stations in Norway and the data from the chosen station will be used in the application. The implementation of station selection was more difficult than expected and some of the stations that are returned from the method are inactive. In addition the number of stations is in the hundreds and a better solution on how to select stations could therefore be implemented (e.g. based on geographical proximity of the station to the user to develop a default value).

As for the actual mobile applications, most identified requirements have been addressed, and it is possible to support the identified scenarios using the application, as partly illustrated above. We had two research questions that we have tried to answer in this project. Regarding the first question, we found out that multiple ways of providing the users with information of their power consumption exist. Several studies have been conducted to study the effects of giving this feedback to the users and in all of them the users' consumption had decreased. The second question is related to how the task was solved since the

resource that is used is strongly connected to the chosen solution. WsKlima and konkuransetilsynet was found as data-sources to be used in this project to give improved feedback through a mobile application.
Through this project we have found that there is currently a growing interest in the power consumption application market and that several companies are developing applications. We have discovered that there are several available resources that can be used to create a power consumption application on a Smartphone (in our case Android) and we believe that an application that includes the measurement of heating efficiency can be a great contribution for Northern countries. The field of heating efficiency is complicated and the algorithms that are used to calculate the efficiency in this application might be improved.
For further work, we are planning to team up with some of the local large scale pilots on the introduction of smart meters as part of the Wireless Trondheim triple-helix collaboration [1].

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