The Power Plant

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ABSTRACT

The Power Plant is a plastic plant, with an embedded lighting apparatus, that displays the electricity consumption in a home through variation of luminosity.

When electric appliances are switched on and power consumption is high in a home the Power Plant fades off, becoming dull and unexciting in appearance. In contrast, when the power consumption is low the Power Plant starts to glow, becoming aesthetically appealing.

Even though it looks like a normal household decoration the Power Plant is an interactive artifact that displays digital information to the occupants of a home. The information is presented in the periphery of the occupants' attention.

Our goal with the Power Plant is to make its users aware about their electricity consumption behavior. Hopefully, this will make them act in a more environmental conscious way and make their electricity bills cheaper.

1 INTRODUCTION

Global warming and climate change are issues that have become something of everyone's concern in recent years. Companies and organizations have started "green campaigns" in order to save the environment, but it is more difficult to make ordinary people take action. The reason might be that environmental friendly products are expensive, difficult to handle or inconvenient.

The Power Plant might be a solution to these issues. It will make people in a household aware of their electricity consumption and does not require much effort from the user. Adaption time is short since a plant it is a very common object in a home setting.

This is a ubiquitous computing project, where the users are not supposed to focus on the technology embedded within the device. The technology blends into the existing environment, to the users and will only react according to the actions of the users, namely their power consumption. As the technology is attached to a plant the product fits into a domestic environment and is not perceived as something out of place.

The Power Plant should only catch the attention of the users when necessary and not get in the way of the everyday activities. It should change one's actions subconsciously.

The Power Plant works in the way that the user does not need to spend time learning how it works. To them it will only be a plant, which will glow at different strengths depending on the number of electric appliances running in their homes.

2 GOAL

The Power Plant should make people more aware of the electricity consumption in their homes. By receiving this information they should also try to become more environmental friendly, minimizing it.

It should also be ubiquitous and seamlessly blend into the household ambience and not be seen as yet another electric appliance. It should suit the atmosphere of the room and look natural.

As all ambient displays, the Power Plant should only operate in the user’s periphery of attention and not be distracting while other daily routines are attended. Therefore, its glow should be soft.

It should also be as decorative as possible for making the room it is placed in more stylish.

3 BACKGROUND

The Power Plant is related to several topics. We looked into environmental issues, ambient displays and how indoor plants affect people around them.

3.1 Environmental Issues

Global warming, resources shortage, pollution, greenhouse gas emissions and environmental degradation are important issues nowadays. People are starting to get more aware of them and feel compelled to help by acting in a more environmental friendly way.

Recycling, reusing, reducing the consumption of water and energy, using public transportations is getting more and more common in developed countries today.

The ubiquitous computing community is also becoming interested in those issues. Currently there are a lot of ongoing projects related to energy conservation, home systems monitoring and automation, environmental monitoring, community planning and so on.

3.2 Ambient Displays

Ambient Displays is a field studying the display of digital information in natural, elusive, subtle and expressive ways in the environment around us.

Ambient Display devices continuously show information without demanding the users’ attention. They just run in the background.

The information is presented in the users´ perceptual periphery, using our five senses (sight, hearing, taste, smell and touch). Choosing which one of the senses to use depends largely on the environment and must be one of the first choices to make when designing this kind of interfaces.

3.3 Using Plants in Interior Design

Using plants in interior design has always been very common. They are pleasing to the eye and have the ability of brighten up a room. They are also an important element in providing a pleasant and calm environment where people can live, work and relax.

According to research carried out in a London hospital in 1995 by the Oxford Brookes University, people react in a more positive way to a building when it has plants inside of it.

In this research, hospital visitors were asked to answer to a test in which they had twenty pairs of opposing adjectives.

According to the results, when plants were placed in the reception area of the hospital, users found it to be "17% more ornate, 17% more interesting, 17% more cheerful, 16% more welcoming, 15% more relaxing, 11% less stressful, 11% more expensive, 11% tidier and 8% quieter".

Another study carried by the Oxford Brookes University in 1999 concluded that people's feel of an indoor area is much more positive, relaxing and stress-free if the space contains plants. Another important conclusion of this research is that people showed a predisposition to sit right next to plants.

4 RELATED WORK

The Power Plant is not a completely original idea. There already exist similar products in related fields.

4.1 Flower Lamp

The Flower Lamp is a lamp that will change its shape depending on the energy consumption in a household. It was developed by STATIC! in order to increase awareness of power consumption among ordinary people.

Figure 1. The Flower Lamp.

The Flower Lamp “blooms” when the energy consumption in a household has been low for a period of time.

4.2 Power Aware Cord

Figure 2. The Power Aware Cord.

Power extension cords are used on a daily basis in most homes. In the Power Aware Cord, this extremely common object was redesigned to visualize, rather than hide, the energy flowing through it. The cord is wrapped in electroluminescent wires, so that the use of electricity is visualized through glowing pulses, flow and intensity of light. It was designed STATIC! and is a joint project between studios POWER and RE:FORM of the Swedish Interactive Institute.

The Power Aware Cord represents a different approach to green design, focusing on user experience and visual representation of relevant issues. It creates an aesthetic and educational connection between the object and the user.

4.3 Real Life LED Lighted Palm Tree

This is an LED-enhanced artificial palm tree. During the day it looks like an ordinary palm tree, while at night the LEDs will turn on, resulting in a green, lively glow effect over the leaves. It is mainly used for decorative purposes: parks, tourist resorts, squares, hotels, city streets and private gardens.

4.4 Yello Sparzähler Online

In collaboration between Villägarnas Riksförbund and the German electric company Yello Strom a system for measuring energy consumption in homes has been tested by Swedish families. Using this system costumers can view the electricity consumption in total (and of each electrical piece of equipment on their own) in real time on a personal website.

The Yello Sparzähler online transmits the data of energy used in the home to the computer of the customer who is able to see to the second from software or a Vista gadget how much energy the refrigerator, stove, hi-fi system, flow heater, etc. actually consume. The system immediately detects electricity hogs and saves energy and money. For the first time, customers are provided full transparency, consumption and cost control of their energy consumption via the personal online account on the Yello homepage. Customers can check on their PCs at any time how consumption and energy costs have changed over months, days and even quarters of an hour. The Yello Sparzähler online turns customers into energy managers in their own four walls.

Yello's Sparzähler concept and Microsoft's software technology make a significant contribution to the efficiency of energy and climate protection with their development cooperation by introducing more customer-friendly and simplified information technology for the home.

Consumption data are transmitted by a communication module (ComBox) that is integrated into the energy meter and will be based on the Microsoft operating system Windows CE. Microsoft products like BizTalk Server, Windows Server and SQL Server ensure the transmission of the consumption data to Yello via the internet. Yello uses .NET and the Windows Presentation Foundation (WPF) for the programming and design of the web site and the software installed on the customer PC.

4.5 Strata/ICC

Strata/ICC is a computationally augmented physical model of a 54-story skyscraper that serves as an interactive display of electricity consumption, water consumption, network utilization, and other kinds of infrastructure data. Brygg Ulmer at the MIT Media Lab designed it.

The two-meter tall model is built of etched acrylic and contains embedded LEDs and microcontrollers. It is an interactive installation for an exhibition of tangible interfaces. It uses shifting light patterns to represent changes in information. Near the base of the model sits a physical icon based interface that allows the user to select between electricity consumption, water consumption or network utilization.

Placing the icon into a 24-hour time wheel allows the user to request the display of resource consumption for a particular time frame. The scale and visual representation of this project are well designed for a museum installation. It was not designed for and does not fit the needs of homeowners. This approach pushes information visualization into the physical world, with a vision of transforming large-scale physical models into new kinds of interaction workspaces.

4.6 AmbientROOM

The ambientROOM was developed in 1998 at the MIT Media Laboratory and is a well-known pioneer project in the field of ambient displays.

The ambientRoom consists of a free standing Steelcase office cubicle room filled up with ambient media displays, which make use of sound and light to transmit information to the user and graspable media controls allowing allow the user to control some of the information streams in the room.

The project is heavily focused in the background/foreground dichotomy. The main purpose of it is to convey information to the user in a peripheral way. In order to achieve this, a combination of airflow, light, physical motion and physical icons are used. For example there is a device that casts water-ripple like shadows in the ceiling according to the activity of a lab’s pet hamster.

5 IMPLEMENTATION

Due to constraints in resources and time we chose to simulate power consumption in a home. Research in measuring it has however been done. This chapter is divided into two parts, one explaining how to measure electricity consumption and another for simulating it.

5.1 Methods for Measuring Electricity Consumption

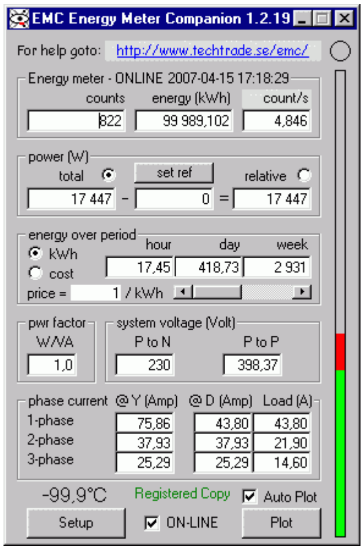
In order to measure the energy consumption in the work Flower Lamp, power transformers are used on each phase. When current goes through the cable, a magnetic field will be formed. A current will be induced to the power transformer. Resistor is connected parallel with the power transformer and one will get a voltage that is proportional to the current in the cables. An A/D converter can be used to measure the voltage over the resistor.

A special sort of A/D have to be used, because others usually have a sample-and-hold circuit, which means that one can't measure all three phases on a three-phase electric power at the same time. The developer used Cirrus Logic CS5451A that has six A/D channels which can take samples at the same time.

The data from the A/D converter can be gathered into a microprocessor, which will do the calculation. The developer has used three ways to communicate with those values, wireless Internet, Bluetooth and memory card.

Other ways of measuring electricity consumption in a household can be found at the Swedish company TechTrade.

On their web site the program EMC (Energy Meter Companion) can be downloaded. This program is a simple calculation which coverts energy to effect but also shows current and energy costs for different time periods. It is available for Windows 95/98/ME/XP/NT/2000. It can be connected to multiple electricity meters at the same time works with both older (analog) and newer (digital) meters.



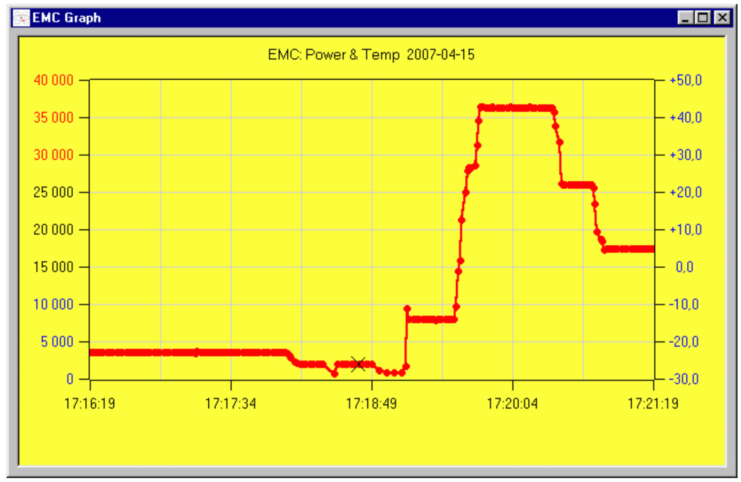


Figure 3. The GUI of EMC.

Figure 4. The graphical output of EMC.

In order to connect the EMC software to a computer a detector is mounted on the electricity meter. On their web site TechTrade offer visitors to buy detectors for different kinds of electricity meters. They also offer information and schematics for constructing your own detector.

To connect an old electricity meter with a rotating disc to a computer there are 3 options.

1. Direct connection with a cable to a COM-port. This is the cheapest way but it comes with the limitations that the length of the wire should not be more than 100 meters. The measuring precision at high effect will be limited by the response time of the computer.

2. Via an EMC-Controller with a cable to the computer. Using an EMC-Controller a stand alone system is created is not dependent on the computer to function. An EMC-Controller contains a microprocessor with an own clock which is used for measure the time interval between the pulses from the electricity meter. Its built in timer will give high precision at all effects. It can also be equipped with a battery which enables the pulse counter to always be activated, for example during a power outage.

3. Via an EMC-Controller with a radio link to the computer. The range is 30 meters indoor and 100 meters outdoors when sight is free.

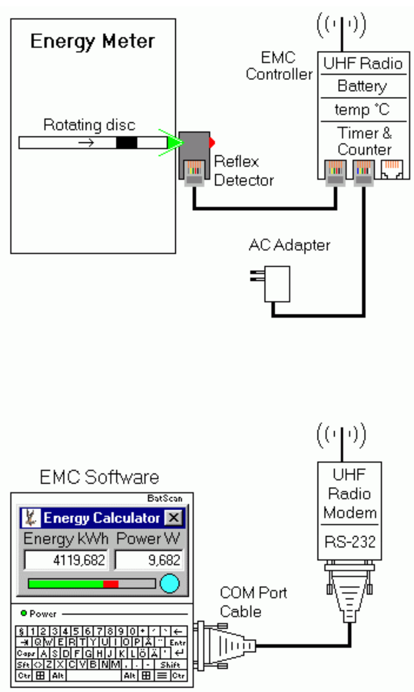


Figure 5. Connection using a radio link.

To connect a modern electricity meter with a S0 output to a computer there are 2 options.

1. Direct connection with a cable to a COM-port. The range can be as long as 100 meters if the TDX signal is connected via a 4700 Ohm resistance. If the S0 output is polarized, the DTR shall be connected to the + pin.

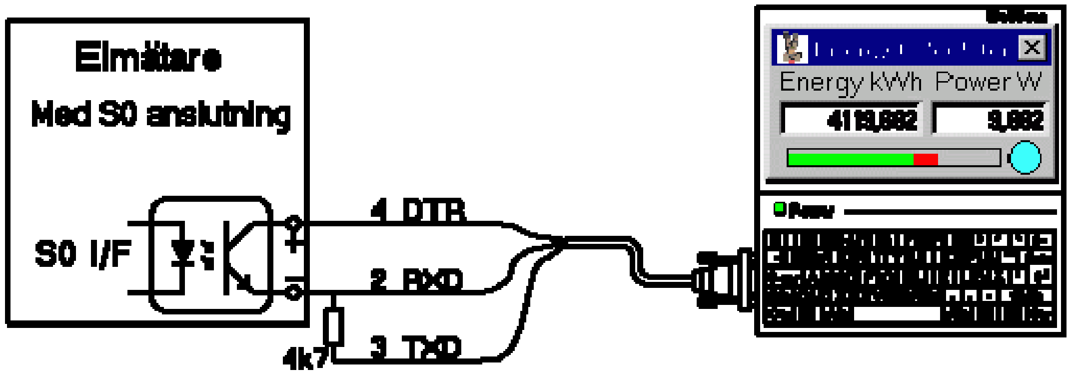


Figure 6. Connection using a cable directly to a COM port.

2. Via an EMC-controller with a cable to the computer. Multiple electricity meters can be connected simultaneously, using cables or wireless connections.

5.2 Implementation of The Power Plant

Although we used simulation for measuring of energy, we connected a real lamp to the simulation as the single real life object. Here we will describe how we connected the plant, the lamp and the simulation.

5.2.1 Arduino

Arduino is an open-source project based on a hardware platform and flexible and easy to use software. The hardware is basically a simple microcontroller board and the software consists in a free development environment.

The Arduino can read sensors and control devices accordingly. This way, Arduino boards can be used to create interactive objects that can work stand-alone or connected to a computer.

Figure 7. Arduino board.

Arduino boards offer many advantages in relation to other microcontrollers and microcontroller platforms. The boards are cheap when compared to other similar solutions, the development environment is simple and easy to understand and the software is cross-platform. It runs on Windows, Linux and Mac OS X.

Also, there is a big online community that provides help for the beginners, as well as already made programs for downloading.

Our project uses two Arduino Diecimila boards. One is properly part of the Power Plant and is basically the core of the whole system. It is used to receive data from the control software and to accordingly drive the three green Luxeon Star LEDs. The second one is not strictly part of the Power Plant and is currently used to sense voltage from a modified Korsby lamp from IKEA.

5.2.2 Lighting Apparatus

We opted to use three green 1 W, 350 mA, Luxeon Star LEDs to light the Power Plant. They are driven by three separate lines because the 5 V voltage provided by the Arduino Diecimila on each of its digital pins it was not enough to simultaneously drive all the three of them as each LED has a voltage drop of 3.2V. In addition to that, the three LEDs are not directly driven by the Arduino PWM outputs, but that is accomplished through one TIP121 Darlington transistor because the maximum current draw from the Arduino digital pins is too low as well. 150 mA are provided, while 350 mA are needed to achieve full brightness. The transistors are powered directly via the AC adapter, relayed through the Arduino VIN pin since that one does not have the current draw limitations of the digital pins.

We have the Arduino board sending a PWM signal with a 0-255 range to the TIP121 transistor base, thus modulating the current flowing through each of the LEDs and consequently its brightness.

The Luxeon Star LEDs are lodged on a Styrofoam support in a triangular arrangement, placed inside the plant itself. Diffusive paper is used to improve and smoothen the lighting effect.

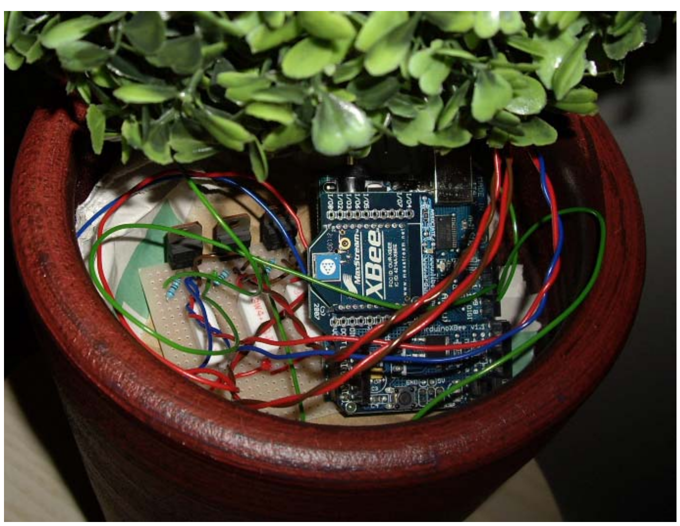


Figure 8. XBee connection inside the vase.

5.2.3 XBee

XBee is a series of commercial RF modules by Digi International based on the IEEE1

802.15.4 and ZigBee set of standards and protocols, focusing on low-cost, low-speed, low-power ubiquitous communication between devices and is intended to be cheaper and less power-demanding than similar technologies such as Bluetooth. XBee is primarily designed to offer a serial data line replacement for embedded applications. Their main advantage is that of being seen as a regular, wired, RS-232 serial ports, and meaning that no additional coding at all is needed to use them.

In our project a pair of XBee modules is employed to provide wireless communication between the Power Plant artifact itself, and a host computer running the control software, namely, the Simulated Electricity Meter.

The first XBee module is connected to the Arduino Diecimila Board residing within the Power Plant via an Arduino XBee shield board.

The other module is connected to the host computer via an XBee USB interface board.

5.2.4 Korsby Lamp

The Korsby lamp was not initially part of the project as we only thought of having virtual appliances, but in a tutoring session we were given the feedback that it would have been nicer and appropriate if we had a physical appliance alongside the virtual ones for our exhibition. As a result we decided to modify a Korsby lamp from IKEA in order to get some kind of output varying according to the current state of the lamp.

The modifications performed on the lamp are:

- Replacement of the power adapter in the lamp.
- Installation of a resistive voltage divider within the lamp circuitry making it possible to scale the probed voltage from 0-12V to 0-4.8V because of the Arduino Diecimila 0-5V ADC range.
- The actual probe wire and a second wire were set into place to give the lamp common ground with the connected Arduino board.

Between the probe and the ground wire we then have a voltage of 0V when the lamp is off, 2.4V when it is on half-brightness and 4.8V when it is fully lit.

The code running on the Arduino reads these values and when a change is detected, it will send a value to its serial output. Our Simulated Electricity Meter then processes this output.

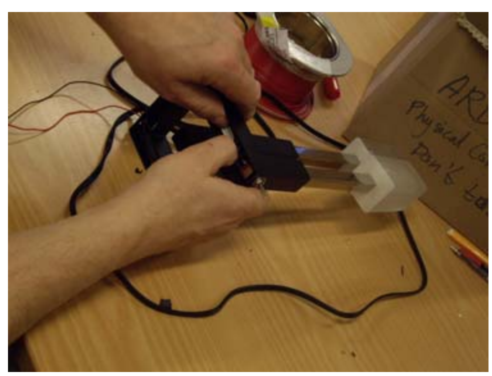


Figure 9. Modifying the Korsby lamp.

5.2.5 Simulated Electricity Meter

Since we decided not to get the power consumption reading from an actual electricity meter we simulated it in a software program. The Simulated Electricity Meter is entirely written in MATLAB, which was chosen because of the relative ease to use serial communication and rapidly set up a GUI within that environment compared to, for example, Java.

Our program features four virtual appliances (Standing Lamp, Ceiling Lamp, TV, and Stereo) and a real one (Korsby Lamp), to mirror our exhibition monter. Currently the values are set to give more emphasis to the real lamp, for exhibition purposes, even if that does not mirror real power consumption data. The appliance layout of the program is saved in a file and is easily reconfigured if such a need arises.

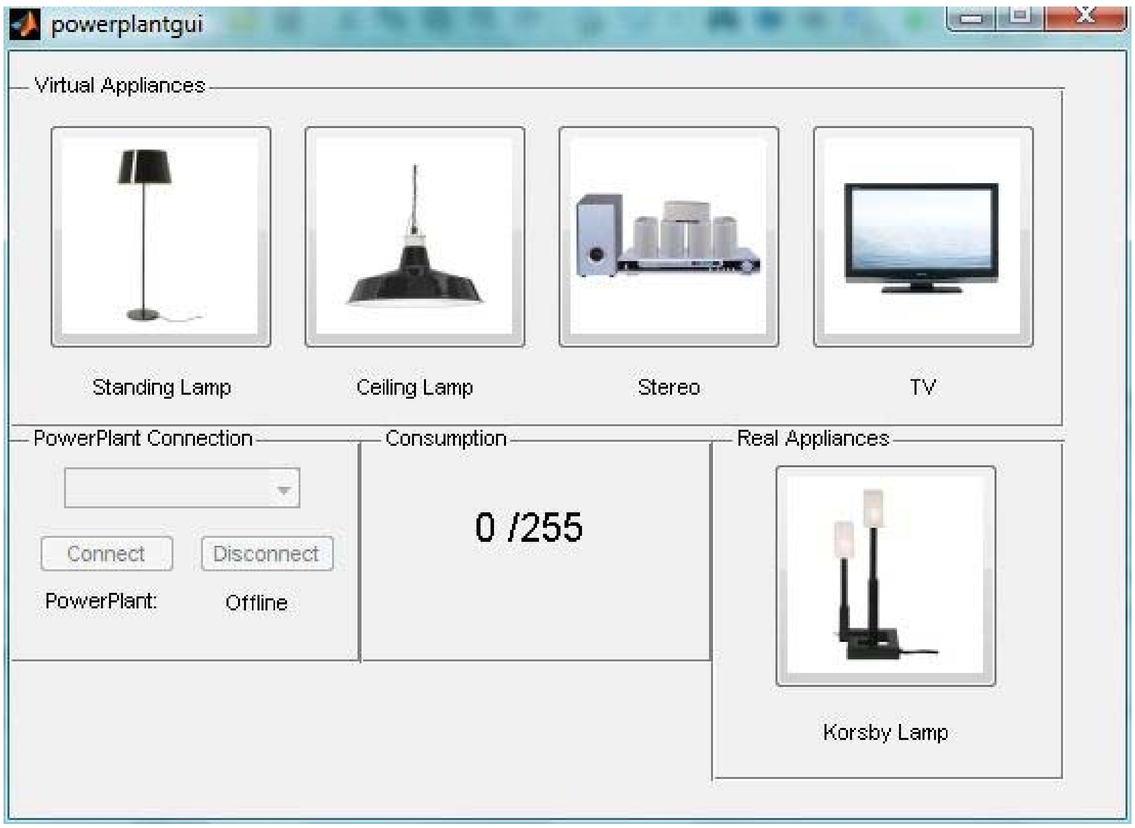


Figure 10. The GUI of the Simulated Electricity Meter.

The operations performed by the Simulated Electricity Meter are as follows:

- A serial communication channel is in place between the program and the Arduino Board sensing the voltage from the Korsby lamp. Each time the lamp changes state (off, half brightness, full brightness) the program is notified of it. Lamp monitoring can be turned on or off pressing the corresponding toggle button on the GUI.
- Four other GUI buttons control the virtual appliances (off, on).
- Each time one of the virtual appliances is toggled on or off, or the physical lamp changes state if its monitoring is enabled, the output value is updated in the text display and wirelessly sent to the Power Plant via another serial communication channel.

5.2.6 System Setup

The whole system can then be represented with the following diagram:

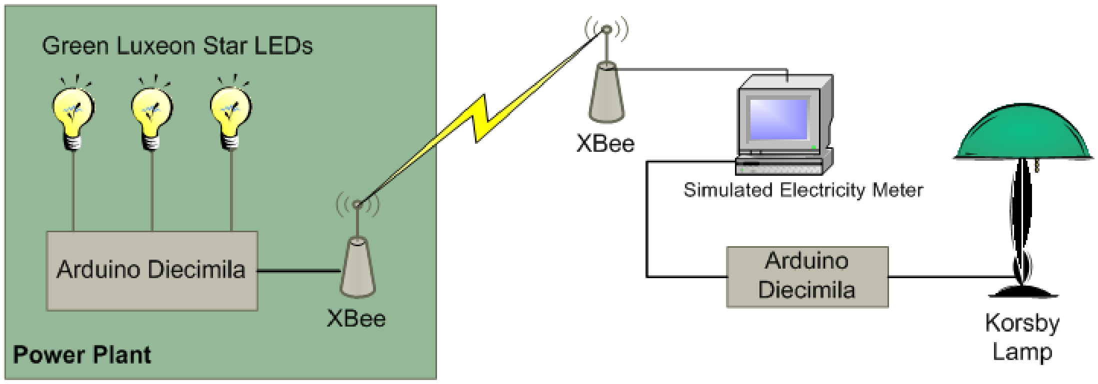


Figure 11. Setup of the entire system.

6 USER EVALUATION

For evaluation we interviewed Mikael, one of our old classmates. Mikael is a 46-year-old man. He lives in a 56m^2 apartment and pays for electricity but not heating. He has the usual electronics at home such as a TV, stereo, video, DVD, printer and two computers (one laptop and one stationary). He cares about his electricity bill and usually turns electronics off when he is not using them, except for his stationary computer.

He found the feedback from the Power Plant to be good looking and not disturbing. He felt that the lighting in the plant might be too weak and unnoticeable and suggested using yellow lights instead of green.

He also wanted to be able to set up the power consumption threshold on his own. If a certain amount of energy is exceeded at any given moment the Power Plant should fade off completely. We found this very interesting and have taken it into consideration for future work.

During our exhibition we got a lot of great feedback from visitors. They liked the concept of the Power Plant, appreciated its looks and understood the point we tried to state.

7 DISCUSSION

During the design process there have been many decisions; some of our original thoughts of functions were changed and evolved as we progressed, while others were dropped. We had to face time, resources and budget limitations, in this chapter we will describe why we chose in favor of some decisions instead of doing things otherwise.

7.1 The Appearance

It is important for the Power Plant to have a nice appearance and to be able to blend in with a home environment. Apart from displaying electricity consumption it should be a decorative item as well. We decided to use a plant since we found that plants something present in most households.

We agreed on having a bushy and green type of plant because we want it to look natural and also because the many leaves would provide cover for the circuitry and act as a light diffuser.

We discussed using a real plant but watering could have been a potential issue due to the risk of damaging the circuitry, another possibility was that of injuring the plant and having it die while fitting it with electronics. A plastic plant is also sturdier than a real one. Therefore, we decided to use a plastic plant.

Figure 12. The two plants sponsored by Blomsterlandet.

We were sponsored by Blomsterlandet and received two types of artificial plastic plants. We had the first type of plant in mind before receiving them, but then we discovered that the round and hollow one would have served our purposes better, as all the electronics could be easily hidden inside of it.

7.2 The Lighting Apparatus

For the lighting apparatus different kinds of LEDs were tried out and tested. The goal was to obtain a pleasant and calm lighting effect. Blinking and flashing lights might annoy the user and were thus ignored. Too bright lighting was discarded due to potential distraction and we decided to resort to green LEDs only since during early prototyping we experienced that other colors were distracting as well.

The Power Plant should be lit up when electricity consumption is low. If otherwise, the user might activate a lot of electronic devices in order to obtain the green lighting. This would work against our goal of decreasing overall electricity consumption.

We considered having the Power Plant display different lighting patterns depending on where in the household appliances are active or not. This was ignored since households are not all the same: there can be apartments or houses, different sizes and amount of rooms, and multiple floors. Mapping the electricity consumption from different appliances in different floors and rooms to specific locations on the Power Plant is indeed technically possible, but would require a custom configured Power Plant according to the specified location of use.

Figure 13. The Power plant dims when much power is used.

We also considered having specific lighting effects, such as shifting color or having certain LEDs on and others off depending on which electronic equipment is activated or not; this idea was rejected as well and instead we decided to implement brightness changes in the lamp according to certain levels of electricity consumption.

The reason behind these decisions is that some equipment will always draw electricity, for example the fridge and freezer in a kitchen, as they are supposed to always be on. Another reason for this was the lack "degrees of displaying freedom" we experienced: the round shape of our plastic plant and the choice of using just green LEDs left us with only the height as a dimension to display different lighting patterns (for example multiple rows of LEDs from the bottom to the top). Lastly, being able to detect which appliances are on and which ones are off requires equipping every one of them with a sensor or using the Sparzähler Online electricity meter from Yellow Strom, which as-of-today is not yet available on the Swedish market.

In order to make our Power Plant glow and fade, we initially thought of using 10mm LEDs placed inside the plant. However, after doing some prototyping, we realized that their light was too concentrated and beam-like for our purposes, as it resulted in an uneven, unpleasant and unnatural lighting effect.

We then tested 5mm LEDs and they turned out to be much better. The downside was that they were too small, and their lights too weak. If we had opted to use them, we would have needed to place a large number of them sparsely onto the plant's surface, needing more output pins on the Arduino board than available.

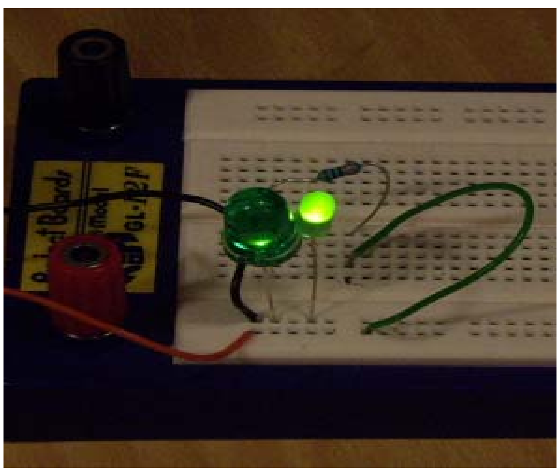


Figure 14. 10mm and 5mm LEDs.

Figure 15. Luxeon Star LEDs.

Finally we tested the Luxeon Star LEDs, which we initially thought would be too bright. However, after placing them in the bottom of the plant, we realized that they were much better than the other tested types. We did not have to use a lot of them to achieve the desired brightness level. Using this kind of LEDs also allowed us to implement viable and meaningful dimming control. The Luxeon Star LEDs were our best choice.

7.3 The Simulated Electricity Meter

We initially intended to measure the power consumption from an electricity meter in a household and then transmit the reading directly to the Power Plant through a wireless connection. However, due to various reasons, this turned out to be unfeasible and the decision of simulating the power central was made instead.

First of all, it would be very difficult to find a suitable power central to use in our project. None of the team members owns or knows someone that owns a house in Gothenburg that could be used. Even if we had a home environment to use, the homeowner might not be legally allowed to install a sensor on the electricity meter.

Second, the project is going to be part of an exhibition. If we were then able to measure the electricity consumption in a real home, an Internet connection would have to be set up in order to relay data from the electricity meter to our location in the exhibition booth, a thing that would require additional coding complexity and time to the project.

Measuring the electricity in the exhibition building is not a viable option either because then the visitors would have to activate and deactivate appliances too far away from our booth even if we were just to get the consumption for one floor only. Johan Redström, the designer director of the Interactive Institute in Sweden, also suggested that we should simulate the electricity meter.

The amount of time available for the completion of the project is another factor that would have made it very hard for us if we had decided to measure real power consumption. We had an average of four weeks to complete the whole project from pre-planning to report writing and we felt that our schedule was already too tight without taking into account the time needed to 'hack' the electricity meter and set up the connection between that and the computer running the software.

Budget constraints as well were something that made us take the decision of simulating the electricity meter. We found out that the Swedish company Techtrade offers some building kits priced just under 300SEK. These building kits allow the measuring of electricity consumption from three different kinds of meters. However, since our total budget was 1500SEK and we needed to buy other crucial components before starting to consider the kits, in the end we had simply not enough money left to afford them.

Finally, we believe that the simulation of the power central still perfectly fits the aims and goals of this course as it led us to learn more about the ubiquitous computing field, its theory and its philosophy anyway and it also had us use our practical skills when developing the lighting apparatus and its connections.

Nevertheless, in this report we described how electricity consumption can be measured from a metering device and how this information can be sent to a computer and further on to a device similar to the Power Plant.

8 CONCLUSION

The Power Plant is a new way to make people aware of their energy consumption habits without having them to make an explicit effort. With the feedback reviewed from the Power Plant its users will hopefully consume less power in order to save money, but also in order to do their part in saving the environment.

Due to our limitations in resources we were only able to simulate an electricity meter in a household. However, with gathered information we believe it will definitely be possible in future work.

As for our goals with the Power Plant, we can say they have been reached.

We got a lot of great feedback for its looks during our exhibition and user evaluation. In our opinion it blends into the household ambience very well.

It is not distracting and stays in the periphery of the attention of its users. During our user evaluation our test subject even thought that it was not distracting enough. Adding two or three more Luxeon Star LEDs to increase the overall light intensity could be a good idea for future work.

Since we have not conducted extensive field studies and because we only simulated an electricity meter in a household we cannot say if it actually will affect people's energy consumption habits. However, we do believe that it has potential to do so since the received feedback concerning the concept has been very positive. People seemed to have gotten the idea of the Power Plant.

9 ACKNOWLEDGMENT

We thank Blomsterlandet for sponsoring us with two plastic plants. We also thank Johan Redström for providing us with information about measuring energy consumption in a household.

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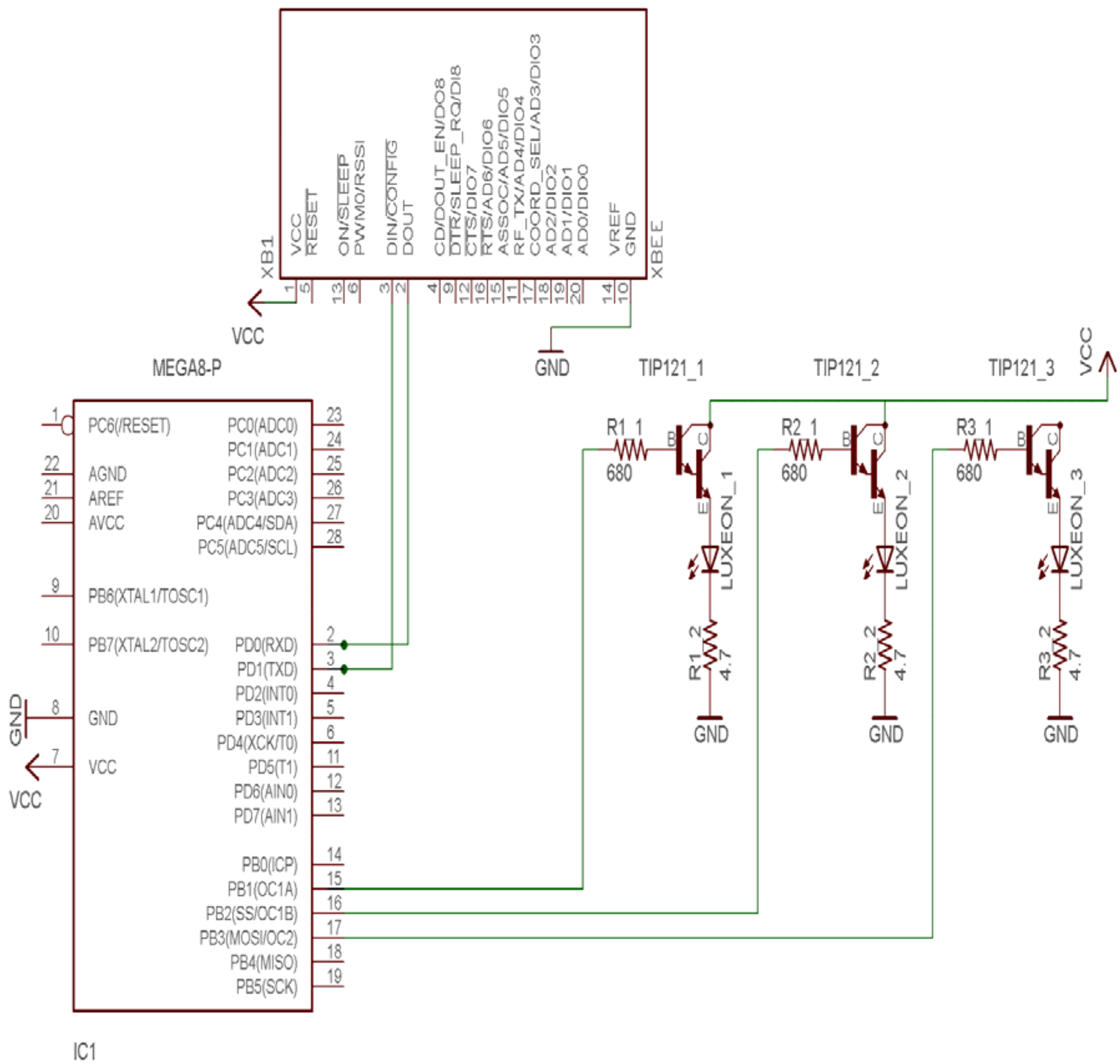
Appendix A: Schematic



Appendix B: Source Code

B.1. Source code for the Arduino Diecimila board driving the LEDs

```
int received=0;
int flag=0;
int lumi=0;
int led1pin=9;
int led2pin=10;
int led3pin=11;

void setup(){
  Serial.begin(9600);
  pinMode(led1pin,OUTPUT);
  pinMode(led2pin,OUTPUT);
  pinMode(led3pin,OUTPUT);
}

void loop(){
  if (Serial.available() > 0) {
    //reads the incoming byte:
    received = Serial.read();
    if (flag==0&&received=='h'){
      Serial.print("h");
      flag=1;
    }
    else if (flag==1){
      lumi=received;
    }
  }
  analogWrite(led1pin,lumi);
  analogWrite(led2pin,lumi);
  analogWrite(led3pin,lumi);
}
```

B.2. Source code for the Arduino Diecimila board detecting the state of the Korsby lamp

```
int lamppin=4;
int lampval;
int lampstatusnew=0;
int lampstatus[10];
int lampstatusold=-1;
int flag=0;
int recv;
int i;
```

```
void setup(){
 Serial.begin(9600);
 for (i=0;i<10;i++){
  lampstatus[i]=-1;
 }
}

void loop(){
 if (Serial.available()>0){
  recv=Serial.read();
  if(recv=='i'&&flag==0)
   flag=1;
  else if (recv=='o'&&flag==1)
   flag=0;
 }

 if (flag==1){
  lampval=analogRead(lamppin);

  if(lampval<100)
   lampstatusnew=0;
  else if (lampval<700)
   lampstatusnew=1;
  else
   lampstatusnew=2;

  for(i=1;i<10;i++){
   lampstatus[i-1]=lampstatus[i];
  }
  lampstatus[9]=lampstatusnew;

  for(i=0;i<9;i++){
   if(lampstatus[i]!=lampstatus[i+1])
    break;
   else if(i==8&&lampstatusold!=lampstatusnew){
    Serial.print(lampstatusnew);
    lampstatusold=lampstatusnew;
   }
  }
  delay(20);
 }
 }
```

B.3. Source code for the Simulated Electricity Meter

Please find it on our website.

Appendix C: Time Plan