AWARE@Home:

Management Tool for Monitoring At-Home Costs and Environmental Impact

Final Report

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REVISED ABSTRACT

The goal of the AWARE@Home system is to enable households to monitor their electricity, natural gas, and water consumption. Before we took over the project, the system had been implemented for electricity but not for natural gas or water. Our goals were to: (1) expand the AWARE@Home system to have natural gas and water monitoring capabilities, (2) improve the system by resolving current flaws, (3) validate the updated system and its components, and (4) add automobile fuel consumption monitoring to the system if time permits.

In this report, we will summarize the work completed on this project, describe how the technology works, and provide suggestions for improvement and future work.

EXECUTIVE SUMMARY

Work has been done on the AWARE@Home project since 2004. When we were assigned this project in January 2006, the AWARE@Home system was only able to monitor electricity consumption. The system consisted of a retrofitted electricity meter, microcontroller, 802.11b wireless serial bridge, NEMA weatherproof enclosure, and software that allowed a user to track his/her electricity consumption via a home computer. The software on the electricity AWARE@Home system interacted with the user through a graphical interface that warned the user if he/she was approaching or set to exceed his/her electricity budget; gave tips and suggestions on how he/she could reduce his/her electricity consumption; and allowed the user to track his/her electricity usage over time.

Our project goal was to expand the AWARE@Home system beyond monitoring electricity usage to natural gas consumption, water consumption, and, if time permitted, automobile diagnostics and fuel consumption. Conceptual work on the expansion to natural gas and water monitoring has been done; however, the expanded system had not previously been completely prototyped or tested. Some critical issues we had to consider in the expansion and improvement of the AWARE@Home system was the requirements of the utility company as well as the requirements of the homeowner. From the utility company's perspective, our system should be able to retrofit onto currently existing meters, be reasonably priced, be low maintenance, and be capable of sending them accurate real-time consumption information. From a homeowner's perspective, the system should be relatively maintenance free, provide real-time consumption information along with price estimates that are easily understood, and potentially save them money on utility consumption bills.

In the electricity monitoring system, the AWARE@Home box is connected directly to an electrical outlet. This works because when there is a power outage, no electricity can be used. Since we were expanding the system to monitor natural gas and water consumption, we needed to investigate alternative powering methods so that the natural gas and water consumption monitoring systems could still track natural gas and water usage information in the event of a power outage. In our working prototypes, we decided to use solar panels as the powering method for the natural gas consumption monitoring unit and we decided to use a paddle wheel to provide power to the water consumption monitoring unit.

Future work needs to be done on the AWARE@Home system for natural gas and water monitoring before a prototype can be installed on someone's house. The main tasks left to do are (1) to find a paddle wheel that supplies enough current and voltage to recharge the battery that powers the water consumption monitoring unit, (2) write a debouncing segment of microcontroller code for the RIOTronics sensor, and (3) have the AWARE@Home data sent directly to DTE so it does not first pass through the homeowner's computer. In addition we did not have time to address automobile fuel consumption monitoring. This is an important issue that would fit in well with the scope of this project. However, working on the natural gas and water monitoring systems took priority over this issue for us and we recommend that a future group investigates a method of implementation for AWARE@Home for automobile fuel consumption monitoring.

PROBLEM DESCRIPTION

The motivation for this project was to reduce the large amount of waste in the consumer home when it came to electricity, natural gas, and water use. The United States consumes about 25% of the world's energy [1], and about 21% of that energy is consumed residentially [2]. It has been our goal, along with others involved with this project, such as DTE Energy Co. (DTE), to develop a way in which consumers could easily track their electricity, natural gas, and water consumption for the betterment of our nation and world as a whole. DTE is centered in Detroit, MI and its largest subsidiaries are Detroit Edison and Michigan Consolidated Gas Co. (MichCon). Detroit Edison provides electricity to 2.1 million consumers in Southeastern Michigan and MichCon provides natural gas to 1.2 million consumers in Michigan.

Our task was to develop or further develop a technology that would allow participating households to both save money and reduce environmental impacts. More specifically, our goal was to try to further develop the AWARE@Home system so that households could monitor their resource consumption patterns instantaneously and effortlessly quantify the cost savings associated with specific actions that were taken. Our goals this semester were to design working prototypes for natural gas and water consumption monitoring, improve the features of the AWARE@Home system, and validate the new system and system components. If time permitted, we were also interested in expanding the system to incorporate an automobile diagnostic and fuel consumption monitor. Ultimately, the goal of our work throughout this semester was to improve the AWARE@Home system in an effort to reduce the amount of waste in consumer households.

To complete our tasks, we worked directly with DTE Energy Co.[1], John Pariseau[2], and Professor Steven Skerlos[3]. John Pariseau has been working on the AWARE@Home project for about one year and has contributed, among other things, by designing the prototype for households to monitor their electrical consumption. This electricity monitoring prototype was installed at the residence of Professor Steven Skerlos in December 2005. Professor Skerlos has been involved with the AWARE@Home since the start of the idea in March 2004. Professor Steven Skerlos has

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a Ph.D. in Industrial Engineering and a B.S. in Electrical Engineering from the University of Illinois at Urbana-Champaign. [4]

CUSTOMER REQUIREMENTS

For the AWARE@Home project, there are two groups of customers with different interests in the project: DTE Energy Co. and homeowners. DTE is sponsoring the project and is a nationwide distributor of electricity and natural gas. In addition to electricity and natural gas, DTE has expressed an interest in implementing the AWARE@Home system for water usage, even though they are not a water-providing utility. [3]

Collaboration with an energy company is vital for the implementation of AWARE@Home in consumers' homes. The energy company is needed to professionally and legally install the system into homes since the electricity, natural gas, and water meters need to be connected to the system. One of the primary goals of the AWARE@Home project is to reduce energy consumption in homes. Reducing energy consumption means that users of the system will be lowering their monthly bills for utilities, so the question must be asked of how an energy company like DTE will benefit from customers paying less for service. There must be some benefits present for DTE in the AWARE@Home project for them to sponsor and encourage the project.

We developed the following customer requirements for DTE in order for the project to be successful from their perspective:

- Improve DTE's public image
    - This will be accomplished through the publics' knowledge that DTE is making an effort to reduce the amount of waste in households
- Reduce expenditures on power from other companies
    - During peak power usage times, DTE can not always meet the demands of its customers. When this occurs, DTE must purchase electricity from competitors. This is a costly practice. By reducing the amount of energy used during peak usage time, DTE will be able to save money.
- Monitor power quality
    - Monitoring power quality will allow DTE to have a heartbeat for their system. DTE will be able to view where power quality is low and allow them somewhat of a preventative maintenance seeing as they can improve power quality before it hits a critical level.
- Have knowledge of when and where power outages occur
    - Knowing when power goes out will allow DTE to take instant action to resolve power outages.
- Optimize repair efforts
    - Being able to monitor where and when power goes out, allows DTE to accurately assess system problems. In addition, it is a common practice for consumers whose power has gone out to request a repair man come out and rectify the problem. After placing this call, power is restored, yet DTE is

    uninformed of this and still sends a worker to the requested site. Being able to know where and when power is out would allow DTE to eliminate this waste of resources. This is in addition to the preventative maintenance previously discussed.
- Eventually reduce or eliminate the need for visits to homes to collect utility usage data
    - After fully validating the system, DTE could eliminate the need to visit household meters and rely solely on the AWARE@Home system.

Homeowners will be purchasing the AWARE@Home system for two main reasons: to save money on utilities and to better preserve the environment. In order to accomplish these tasks the system must be appealing to customers with varying degrees of knowledge about computers, energy, and finances. The software used in the system will have options suited to both basic and advanced users and hopefully will be set up in a way that each user will take an interest and eventually become very knowledgeable about how to save money and reduce environmental impact from home energy usage. The software will have several different methods of tracking costs for energy usage including bar graphs and pie charts and will alert users when they are on pace to go over their target monthly energy budget.

We developed the following customer requirements for homeowners in order for the project to be successful from their perspective:

- Reduce monthly utility bills
- Have easy access to tips on reducing electricity, natural gas, and water usage
- Outdoor components of system are weatherproof
- System is inexpensive
- System is aesthetically pleasing and not too large
- Wireless data transmission is FCC and IEE compliant
- Software is easy to install
- Software works well for both beginning and advanced level users

In addition to the customer requirements previously listed, there are several more that overlap between DTE and homeowners. The following are customer requirements that are of crucial importance to the project both from DTE’s and homeowners’ perspectives:

- Positively impact the environment
- System is reliable
- System is accurate
- System can be installed quickly
- System can be used during power outage
- Current meters are compatible with system

ENGINEERING SPECIFICATIONS

We developed engineering specifications for our project based on the existing AWARE@Home system for electrical consumption monitoring and our proposed systems for natural gas and water monitoring. These specifications, listed in Table 1, address some of the most important areas of the project including resolution of measurements, power requirements, and installation. We attached a target to each of the specifications that we used or achieved during the course of our project.

Table 1: Engineering Specifications for AWARE@Home Project

Engineering Specification	**Target**
Allow consumption information to be sent wirelessly from microcontroller to home computer	802.11b network
Allow consumption information to be sent from home computer to DTE	XML gateway
Coding language for microcontroller	C
Coding language for AWARE@Home Software	Visual Basic
Meters attached to AWARE@Home box can be installed in line with current meters	Yes
Electrical and Natural Gas AWARE@Home boxes are weatherproof	NEMA enclosure
Water AWARE@Home box can attach to pipe or ceiling	Yes
Natural Gas and Water AWARE@Home boxes can function normally during power outages	Yes
Electricity AWARE@Home box can store previous consumption data during power outages	Yes, for 12 hours
Sufficient power for each AWARE@Home box to run	3 W
Resolution of electric meter readings	1 kWh (currently 10 kWh)
Resolution of gas meter readings	1 ft^3
Resolution of water meter readings	10 gallons
Measurement error	±5%
Number of days without sun that the solar panel array could store charge	10 days

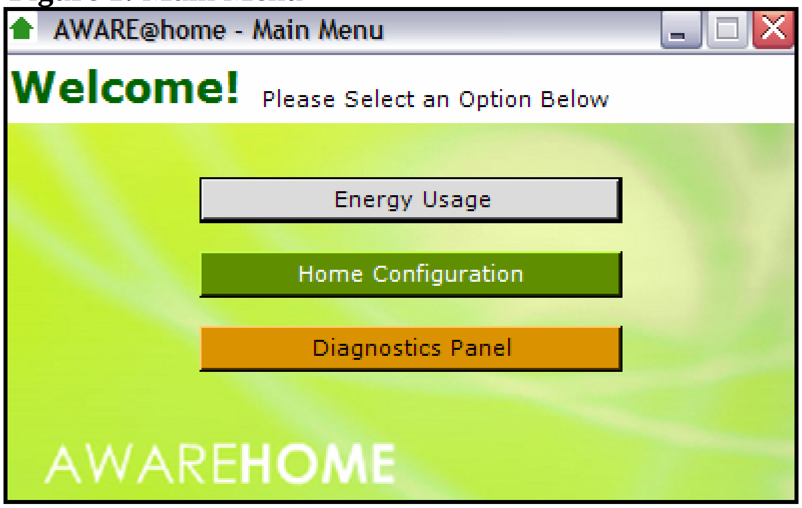
VISUAL BASIC CODING OVERVIEW

In the previous AWARE@Home system, electricity consumption data was read in and manipulated to produce figures that allowed users to easily monitor their electricity consumption. The incoming information was also logged and sent to Detroit Energy Company (DTE). The following further describes these processes.

The Visual Basic coding comes into play after information is sent from the AWARE@Home box wirelessly. Data sent from the AWARE@Home box is in string form. Inside of this string, the time, number of pulse counts per day, and total cumulative counts are stored. Power quality information is also sent with this string. After information is sent out from the box, it is picked up by a local computer and routed to the Visual Basic code, continued within the server. Upon being received, the server parses the data into a usable form. Next, data is then logged and routed to other part of the server. [15]

When the AWARE@Home Visual Basic software is started, the main display window is shown, as seen in Figure 1 below . From this window, a user can navigate to the window of their choice.

Figure 1: Main Menu



Diagnostics Panel

The Diagnostics Panel is the starting point for the inflow of information. Inside of the Diagnostics Panel, information sent by the microcontroller as well as the real-time status of the microcontroller can be viewed. From this panel, users can manually send XML files to DTE's gateway, create an XML file on their computer, update the CVS log file, or access their communication port (com port) setting, as seen in Figure A1.

A user can access their com port settings by clicking on the "Com Set" button. This prompts a window which displays the current setting for which com port is being used as well as a real time information stream updated every thirty seconds. This can be seen in Figure A2. Inside of the coding for this panel, the communications port used is hardcoded to a default of communications port eight. This is set to match the communications port settings on the wireless router inside of the AWARE@Home box. If the user desires, they can manually change the com port being used by inputting the desired port and clicking the "Change" button.

Coded inside of the Diagnostics Panel is a timer set to meet DTE's requirements. DTE requires data to be sent to an XML gateway for processing. The timer counts down and posts an XML string to DTE's gateway every hour, or immediately when a Power Quality Alarm is received in the event that power quality drops below a certain critical value. Inside of this post to DTE, information of power usage or the power quality event is sent.

Information is logged to CSV files containing data for each day/hour, on a monthly basis. At the beginning of the semester, the writing of CSV files had not set to a timer and had to be manually done through the usage of the "Write CSV" button. This meant that data potentially could have been lost if the CSV files were not updated in a timely fashion. However, before information could be logged, template CSV files had to be created. In the previous system, these logs only existed for electricity (i.e. e2005-11.csv, e2006-2.csv), where e stands for electricity. Inside of these log files, a timestamp, hourly pulse count, and total cumulative pulse counts were written. These logs allowed the Visual Basic application to display, plot, and manipulate data.

Home Configuration

Inside of the Home Configuration panel, seen in Figure A3, users can navigate to input various household attributes as well as cost and spending information. Coded inside of this program is a global preferences array. This array is used to store customer inputs so it can be used globally throughout the program. Currently, the system, as well as the array, is set up to only take in and store electricity consumption data.

From the Home Configuration panel, users can access one of the most important panels in the system, the Preferences panel, shown in Figure A4. In this panel, the user inputs their total electricity budget and the electricity rate, the cost of electricity as obtained from the utility company. Users can also set how often they would like to see pop-ups and alarms. Pop-ups and alarms are triggered when users are on pace to exceed, or have exceeded their monthly budget. The input budget and rate are stored to the global preferences array and are the basis for calculations done in the "Energy Usage" panel.

The highlight of the Home Configuration panel is that it allows for different skill level users to interface with the software accordingly. Higher level users can use this panel to input specific information unique to their households. These users can enter a variety of information such as information about heating and lighting, whether or not they have a dishwasher, their stove and oven properties, and even information about their fridges and freezers. After entering this information, high level users can visit the Energy Usage panel and make a plot of energy consumption for heating, lighting, fridge, stove, and washer costs per month. Conversely, lower level users do not have to enter this information. They can opt to use these features, but system operation is not contingent upon it.

Energy Usage

Inside of the Energy Usage panel, users can view their current electricity consumption, spending, and projected total spending per month. Within the Energy Usage panel there are seven panels: Budget Overview, Electricity Usage, Appliance Usage, Vehicle Usage, Water Usage, Gas Usage, and Plots. These panels will be described in detail below.

<u>Budget Overview</u> *(Figure A5):* This panel allows users to view their set budget, current monthly spending, and projected monthly spending. Spending information is displayed numerically along with two bar graphs illustrating the current and projected spending as percentages of the set budget. Currently, these values reference only electricity consumption data.

<u>Electricity Usage</u> *(Figure A6):* This panel allows users to view their set electricity budget, numerical values of their electricity usage and projected costs, and bar graphs illustrating the current and projected percentages that have been used of the set electricity budget.

Appliance Usage: This panel has not been set up yet because investigation into the prototype is still being conducted.

Vehicle Usage: This panel has not been set up yet because investigation into the prototype is still being conducted.

Water Usage: This panel has not been set up yet because investigation into the prototype is still being conducted. This panel will be very similar to the Electricity Usage tab.

Gas Usage: This tab has not been set up yet because investigation into the prototype is still being conducted. This panel will be very similar to the Electricity Usage tab.

Plots (*Figure A7-Figure* A8*):* Under this panel, a homeowner has two plots that he/she can view. One plot allows a homeowner to view a bar graph of the electricity costs per day in the month. The other plot allows the homeowner to view a line graph that progresses up to the total monthly electricity cost on a per-day basis.

VISUAL BASIC CODING (USER INTERFACE)

A modification to the user interface was needed so that consumers can monitor their gas and water usage similarly to the way they monitor electricity consumption. To determine how to accomplish this task, an understanding of how the structure of the current code was needed. Upon determining how the system worked, concepts on how to achieve our goals were generated. These concepts were then analyzed and the best concept was selected.

Concept Generation

Through a series of brainstorming sessions, two concepts were generated. These ideas are outlined in the following paragraphs.

The first concept called for the creation of new Visual Basic code for each additional utility added to AWARE@Home. This would mean that each utility would have its own software package that operates independent of the other utilities.

The second concept called for a complete system overhaul. In this concept, the current Visual Basic code would be modified so that all three utilities would have their information logged, sent to DTE, and displayed in one central program.

Concept Selection

To select which concept we wanted to proceed with, we consulted John Pariseau. John, as previously stated, has been involved with the AWARE@Home project for some time. Currently, he is working on updating the existing Visual Basic code in an effort to make it “smarter.” Smarter is defined as the system being able to provide feedback to a user input.

In discussions with John, he pointed out that the existing Visual Basic code had been created with the intent of water and gas being implemented directly into the existing code. To support this claim, John pointed out the "Water Usage" and "Gas Usage" panels located inside of the "Energy Usage" panel. John also pointed out how the "Budget Overview" and "Electricity Usage" panels were essentially displaying the same information. All of these observances reinstate the fact that the original programmers intended for all three utilities to be a part of the same software package.

When presented with the current concepts, John advised us to implement water and gas directly into the current system, i.e. use one software program for all the utilities.

Creating a single program to manage the data from all three utilities would allow users to quickly input their desired settings and access information on their utilities without having to switch between different programs. Having all three utilities in the same program would also allow for the utilization of the "Budget Overview" panel and would also allow users to get an overview of their utilities through one screen as opposed to three.

Creating separate programs for each utility would work just as well as implementing them all into one. However, implementation of a single program cuts down on the number of steps a user must take to access information, thus making the system more user friendly.

Selected Concept Description

We decided that implementing water and gas directly into the existing software would be the best course of action. To accomplish this task, many things needed to be done. A brief description of the changes that needed to be implemented in each section of the existing Visual Basic code is outlined below.

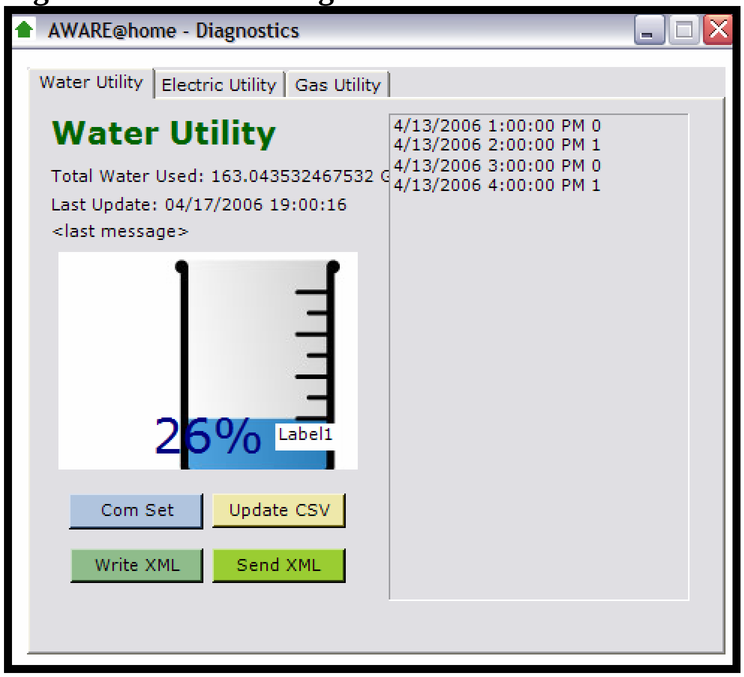
When the AWARE@Home Visual Basic software is started, the main display window is shown, as seen in Figure 1 on page 11. No modifications were made to the coding of this panel; however, many modifications needed be made to the ensuing panels.

Diagnostics Panel

The Diagnostics panel is the starting point for the inflow of information. Therefore, this is where the first coding modifications needed occur. The Diagnostics panel was set up to only handle the inflow of information for electricity consumption. To fix this, a new structuring for this panel was needed.

In the restructuring of the Diagnostics panel, the existing panel needed to be adjusted to include new Water and Gas tabs. This concept is shown in Figure 2.

Figure 2: Modified Diagnostics Panel



The two new tabs created to handle the water and gas utilities were modeled directly after the existing electricity setup. Each form displays usage information, the time when the information was last updated, the last message sent, and the timer counting down the time until the next XML is sent. In addition to these features, each form also has its own Com Set, Update CSV, Write XML, and Send XML buttons, and a real time information viewing window.

In order to make the new water and gas form work, many tasks had to be accomplished. Among the first things that needed to occur, is the creation of a Com Set panel for each of the new utilities. These new panels were structured the same as the electric Com Set panel. Inside of the coding for each of these panels the com port utilized was hard-coded. This com port setting matched that of the DPAC Wireless Serial Link inside of the corresponding AWARE@Home box. It is important to note that each utility must use a different com port. Each of the new Com Set windows has the ability to change the current com port manually and displays a real time information stream updated every thirty seconds. Creating these new panels was vital to ensuring that information for the newly added utilities could be taken in by the system.

After enabling the system to receive water and gas information, the current timer inside of the Diagnostics panel was coded to act as a count down for all three utilities. This timer counts down and triggers the posting of XML strings to DTE's XML gateway. The water and gas utilities were not enabled to read power quality information and therefore they need not be coded to post in result of a power quality issue. Information for all three utilities was setup such that it is sent out on an hourly basis. Before anything could be posted for water or gas, DTE needed to be contacted to create XML gateways for each newly added utility. Using the existing timer for all three utilities allowed these system modifications to meet DTE's requirements of having information for each utility sent to an XML gateway for processing.

In addition to posting XML strings, strings of information for each utility are logged hourly to CSV files. These files are updated every thirty seconds. The logging of information hourly was accomplished by using the existing hourly timer to not only trigger an XML posting, but also write to the CSV files. These files contain data for each day/hour, on a monthly basis. Currently, template files exist for electricity only. Before being able to log information for water or gas, similar templates were created. The existing labeling system is set up to handle the addition of water and gas. Electricity files are written in the form of e2005-11.csv, where e stands for electricity, 2005 represents the current year, and 11 represents the month. This logging system allows for the first letter of each filename to represent the utility being logged. Therefore, water and gas were represented by "w" and "g" respectively. Inside of these log files, a timestamp, hourly pulse count, and total cumulative pulse counts are written.

Home Configuration

Inside of the Home Configuration panel, the Preferences panel resides. This is the only panel that needed to be modified inside of the Home Configuration panel.

The Home Configuration panel was set up to receive a users total electricity budget and their electricity rate, the cost of electricity. In this panel, users also set how often they would like to see pop-ups and alarms in regards to electricity usage. The input budget and rate are stored to the global preferences array and are the basis for calculations done in the "Energy Usage" panel.

In order to expand the system for water and gas, text boxes to receive water and gas information were added. A text box for the total budget and current cost of both water and gas were also added. Additionally, the existing alarm settings section was expanded to allow users to set their preferences on when they wish to receive alarms for water and gas.

In order to make the modifications to the Home Configuration panel work, the global prefs array needed to be expanded. This array was expanded to store all new inputs from the preferences panel so they can be used globally throughout the program.

Energy Usage

Inside of the Energy Usage panel, modifications are needed to update the many panels located inside. Below describes the modifications that will occur to each panel.

Budget Overview (Figure A5): This panel will need to be modified to display information on the cumulative total and projected spending of all three utilities. To accomplish this, the cumulative total and projected spending of all three utilities will need to be calculated. After being calculated, the reference locations for the values displayed on the page needed to be changed. Also, the reference values for the two bar plots needed to be changed to these new cumulative totals.

Electricity Usage (Figure A6): This panel had no modifications.

Appliance Usage: This panel had no modifications.

Vehicle Usage: This panel will have no modifications.

Water Usage: This panel was modeled off of the Electricity Usage panel. On this panel, the users set budget, current cost of water used, and a projected total cost are displayed numerically. To compliment these values, two bar graphs were added to visibly represent the percentage of the current budget used and the projected total percentage used. A gauge was also added to show the current percentage used of the utility budget.

Gas Usage: This panel was modeled off of the Electricity Usage panel. On this panel, the users set budget, current cost of gas used, and a projected total cost are displayed numerically. To compliment these values, two bar graphs were added to visibly represent the percentage of the current budget used and the projected total percentage used. A gauge was also added to show the current percentage used of the utility budget.

Plots (Figure A7-Figure A8*):* In this panel, all plots needed to be updated to display the cumulative usage total on each graph. In order to accomplish this we needed to reference information to each plot correctly. The reference for total spending and projected total also needed to be updated accordingly.

SENSORS

Before we were able to create new systems, the way in which data was collected from the water and natural gas meters needed to be addressed. To address this issue, we generated some concept ideas, analyzed the ideas we came up with, and finally selected the best concept for each utility.

Background

Before discussing concept generation for sensors, it is important to first understand exactly what the function of a pulse sensor is in our project. A pulse sensor is used as a component within the AWARE@Home box that sends a pulse to the microcontroller, also located within the AWARE@Home box, whenever a milestone is reached. A milestone is different for each utility; for example, for natural gas, the milestone is defined as one cubic foot. So, for every cubic foot that is consumed, a pulse is sent out. Simply, a pulse in terms of our project is a notification that is sent out to notify the AWARE@Home box that a change in utility consumption has occurred. Our goal is to send out a pulse as often as we can so that we can achieve the highest resolution possible while considering power supply issues.

Concept Generation

Through a series of brainstorming sessions and much research, we were able to come up with two methods of sending pulses: hall sensors and the RIOTronics pulse sensor. Hall sensors were currently in place for electricity consumption monitoring. We thought that our new systems for natural gas and water would be very similar to the setup for electricity. The second concept we came up with, RIOTronics, operates very similar to a hall sensor abut requires less power, which is a great advantage because the size of the power supply systems would decrease. The RIOTronics sensor, however, requires more modification of the microcontroller coding.

Concept Selection

The biggest benefit of the RIOTronics sensor was that it required less power than the hall sensor. With a hall sensor based system, power constantly has to be supplied to the sensor for it to be able to send out a pulse. The RIOTronics sensor based system, on the other hand, only requires power when a pulse needs to be sent to the AWARE@Home microcontroller. Thus, the required power will be strictly dependent on how accurate we want our sensor to be.

Using RIOTronics, it is very easy to be as accurate as the nearest 1/100 of a cubic foot. Engineering logic will always guide us to choose the most accurate device as possible, but two issues of cost arise with accuracy in our project. First, the more accurate the sensor is, the higher the monetary cost of the sensor. We have chosen to stay in the range of 2-1/4 cubic foot accuracy due to sensor costs. Secondly, we know that with a more accurate sensor, more pulses are required, which would require more input power, knowing that every pulse requires 2-5 V. With more power required, the task of choosing a power supply becomes more difficult. Thus, the goal is to minimize the power consumption of the unit, while being as accurate as possible.

An average household within the United States of America consumes approximately 82,000 cubic feet of natural gas a year. [2] From our research, we found out that most natural gas utility bills are only read to the nearest hundredth. We feel that if bills are measured to the nearest hundredth reading out to the nearest two cubic feet, the estimation should be more than sufficient for a homeowner's needs. Thus, we have chosen to be slightly more accurate than what we expect will be necessary, to be on the safer side of things. We chose to purchase a RIOTronics unit that read to the nearest cubic foot.

The other benefit that the RIOTronics sensor possessed was its reliability and easy installed. The RIOTronics sensor is easily clipped onto the front gauge panel of a gas meter and is also wired to and mounted partly on the back of the meter. Installing a RIOTronics sensor should be a very easy task for any utility meter technician once they have been introduced to the unit. The previously implemented electricity AWARE@Home system used hall sensors, which were installed using an unreliable superglue adhesive.

Selected Concept Description

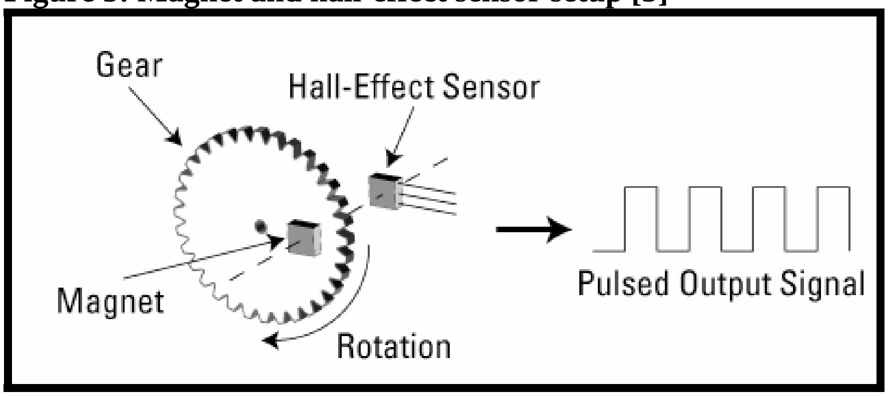
As a group, we decided to alter the natural gas sensor selection from a standard hall sensor to a RIOTronics sensor. RIOTronics prides themselves on being a "meter reading systems manufacturer". They have engineered and manufactured meter retrofit pulse devices for over 10 years now. [1] A RIOTronics sensor was chosen because it holds all of the same features as the hall sensor with a few important benefits.

Although there were great benefits to adopting our systems to use a RIOTronics sensor, we chose to use a hall sensor system for the water consumption monitoring system. We made this decision because RIOTronics does not produce a sensor to accumulate water consumption needs. We have not ruled out the possibility of later adopting a new system if something arises. However, due to time constraints, we chose to move forth with our project using hall sensors for the water consumption AWARE@Home box.

Water Consumption – Hall Sensors

Inside of the water meter, a system of gears works to produce circular dial or odometer read-outs that display the amount of utility usage. During the retrofitting of the water meter, a magnet was installed on the face of the lowest revolution gear away from the rest of the gear train. To complement this magnet, a Honeywell model SS441A hall sensor was installed on the back mount closest to the magnet. The hall sensor was installed relative to the magnet's path of travel. Each time the gear turns, the magnet passed by the hall sensor, tripping it. Upon being tripped, the hall sensor outputted a pulse. Figure 3 illustrates this process. [3,4]

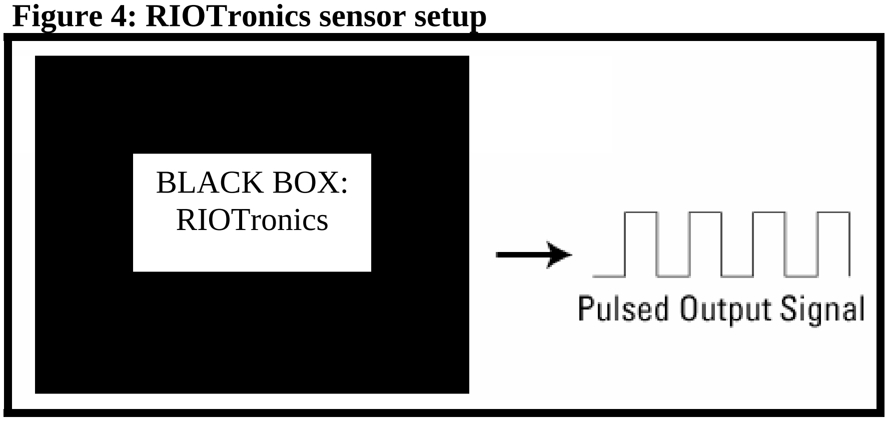
Figure 3: Magnet and hall-effect sensor setup [3]



Natural Gas Consumption – RIOTronics

We were under the understanding that a RIOTronics unit works very similar to our hall sensor unit. However, our group was not familiar enough with electronics and circuitry to understand the exact difference. We asked a few of RIOTronics contacts to further explain the system to us; however, they did not want to fully explain the system to us because of company policy. Therefore, we have designed Figure 4 very similar to Figure 3 but with an engineering black box component used to represent the RIOTronics unit.

Figure 4: RIOTronics sensor setup



We know that the RIOTronics unit has some oscillations in the pulsed output signal and needs to be debounced to be interpreted properly by the microcontroller. In order to do this, we will need to add a function into the microcontroller coding to accomplish the debouncing. Further consultation with RIOTronics and John Pariseau would need to be done for help with this issue.

POWER SUPPLIES

Before we built our new systems, we had to address the powering issues for the monitoring systems. Using an AC power supply worked well for electricity, but weren't as ideal for the natural gas and water consumption monitoring systems. To address this issue, we generated power supply concepts and did some analysis to see which power supply concept would work best for the natural gas consumption monitoring system and water consumption monitoring system.

Concept Generation

Through online research and team brainstorming, we came up with several concepts for the powering system of the AWARE@Home utilities monitoring system. The ideas were: (1) electricity with backup memory (current electrical monitoring system design), (2) chemical reaction, (3) spinning magnets or electromagnets, (4) springs and/or weights, (5) solar power, (6) oscillators, (7) flow power, (8) wind power, and (9) animal power.

There were multiple ways we could have set up the AWARE@Home system. Ultimately, however, the goal was to be able to monitor electricity, gas, and water consumption. The current system for electricity simply has the electricity AWARE@Home box connected to an AC power supply. This works well for the electricity monitoring system because once power goes out, the people in the house will no longer be consuming electricity and hence it is not necessary for the electricity monitoring system to be able to track usage for an extended period of time. However, for the gas and water monitoring systems, homeowners will likely still be able to use gas and water when there is a power outage; therefore, the use of an electrical power supply is not ideal. Therefore, we had to find a way to power the natural gas and water consumption monitoring systems.

Our goal was to determine which power supply would work best for each individual monitoring system and devise a way to implement it into our system. The decisions we made regarding the power supply concept selection are detailed below.

Concept Selection

To help aid us in our power supply concept selection, we made a Pugh Chart (see Table 2), which uses design criteria and the weight of each design criteria to help determine which designs we should look into more than others. The weighting system was developed by assigning weights in proportion to the level of importance of each design criteria with the weights summing to 100. From our Pugh chart, the flow power concept came out on top with 488 points. The spinning magnets idea also received a high ranking, followed by springs and/or weights and oscillators. Although solar power ranked second to last on our list (based on the Pugh chart), we wanted to further investigate this because of its great potential for gas monitoring. Looking at the top design criteria (provides sufficient power, reliable, works during power outages, and works in a basement), one can see that animal power, chemical reaction, and wind power concept ideas received low scores. Therefore, we did not look into these designs as extensively.

Table 2: **Pugh Chart for power supplies**

		Designs								
Design Criteria	Weight	Electricity with Backup	Chemical Reaction	Spinning Magnets	Springs and/or Weights	Solar Power	Oscillators	Flow Power	Wind Power	Animal Power
Inexpensive	7	3	3	9	9	1	3	3	1	9
Easy-to-install	7	3	1	3	3	1	3	1	1	3
Reliable	14	3	1	3	3	1	3	3	1	1
Works in the dark	7	3	9	9	9	1	9	9	3	9
Works during power outages	10	3	3	9	9	9	9	9	9	9
Provides sufficient power	17	3	1	3	3	3	3	3	1	1
Works while homeowner is away	7	3	1	3	3	3	3	1	3	1
Aesthetically pleasing	4	3	1	3	3	1	3	9	1	1
Compact	5	3	1	3	3	1	3	9	1	1
Works in a basement	12	3	3	3	3	1	3	3	1	1
Environmentally friendly	5	3	1	3	3	3	3	9	9	9
Renewable energy source	5	3	1	9	9	9	9	9	9	9
Total	100	300	214	474	444	278	432	488	288	386

Once we had a few designs that we could concentrate on, we researched each of the designs and tried to learn as much as we could about each powering system. A description of the information we found for each of the top designs is described in the following paragraphs.

Electricity with Backup

The electricity with backup option (currently being used for the electricity monitoring system) was a very good option for the electricity monitoring system because once the power goes out, homeowners can no longer use their electricity and therefore no electricity usage has to be tracked. The backup option would allow the AWARE@Home system to store the counts (i.e. the amount of electricity used to date).

Solar Power

Since the electricity with backup option would not work to power the natural gas or water monitoring systems in the event of a power outage, we heavily investigated the use of solar power and determined that it was a viable powering system option for these two utilities. Solar power had many advantages associated with it, some of which included:

- Sunlight energy is a renewable energy source, so it will not run out
- Solar power is an excellent way to charge a battery that could run the AWARE@Home box
- The solar power system would provide almost continuous charging of the battery, instead of solely depleting the battery in the system with no way of recharging it
- The solar power system would be very reliable if there are a reasonable amount of sunny days in the area in which the AWARE@Home system is installed
- The solar power system is virtually free after the initial equipment cost
- The solar power system is good for the environment because it does not produce any harmful greenhouse gases—a positive externality [5]
- The solar power system is also fairly low maintenance after the initial installation

Although solar power has many advantages, it also has its disadvantages, some of which include:

- Solar panels are very expensive; however, their cost is slowly dropping
- The sun does not necessarily shine on a continual basis, which poses great problems for areas where there are many cloudy days in a row, as the solar power system has to be capable of powering the AWARE@Home system during these periods of time.
- In cloudy areas, the system would have to contain a large battery to make up for the days that the sun can't provide enough energy to the AWARE@Home box. Depending on the maximum number of cloudy days in a row, the battery size (and hence cost) changes drastically.
- Since sunlight energy is a diffuse energy source, each solar cell only absorbs about 15% of the sunlight's energy. [6] This means that you need many solar panels to collect the necessary amount of power.
- If a small part of a solar module is shaded, a significant amount of energy is not absorbed by the system. It is important to know the angle of orientation for the solar cells to obtain maximal sunlight absorption.[4]
- The solar panels need to be cleaned with warm water and dishwashing soap, with the frequency of cleansing depending on the weather conditions at a particular location. Cleaning the solar panels ensures that light is transmitted properly through the cell and optimizes the performance of the solar panels.

Spinning Magnets

The basis for the spinning magnets concept was electromagnetism. If electric current runs through a wire, a magnetic field is created. A regular electromagnet works by using the electrons produced in a battery to create the current through the wire and hence the magnetic field. In our application, however, we could have potentially found a way to use current or magnetic fields already present in the utility meters to charge a battery or capacitor. In our research on spinning magnets and electromagnets, however, it seemed as though it would be difficult to actually do this because the magnets in the gas and electricity meter were not that strong and didn't turn very often. From our research, we determined that harnessing the necessary amount of power to run the AWARE@Home system would be tough with this method.

Flow Power

From our investigations, we determined that flow power could be achieved by installing a paddle wheel inside the water inlet pipe that connects to the water meter. As the homeowner uses water, water flowing through the inlet pipe would spin the paddle wheel, which would act like a small turbine, thus generating power from its spinning motion. We thought the paddle wheel would be able to provide sufficient power for the water monitoring system and would also be very affordable, an excellent advantage for the AWARE@Home system. One disadvantage of this concept was that power will not be supplied while the user is away from home since water is not being used. However, we since very little or no water would be consumed during this time, it was not as important for the paddle wheel to be able to power the AWARE@Home box.

[4] "The angle of the solar array can be anywhere from your latitude plus 15 degrees to latitude minus 15 degrees for a yearly fixed mount position. Your latitude offers the best year-round position. By biasing the array 'latitude plus 15 degrees' you will get slightly more [sunlight intensity] during winter months. A 'latitude minus 15 degrees' will bias the array to summer months." [7]

Selected Concept Description

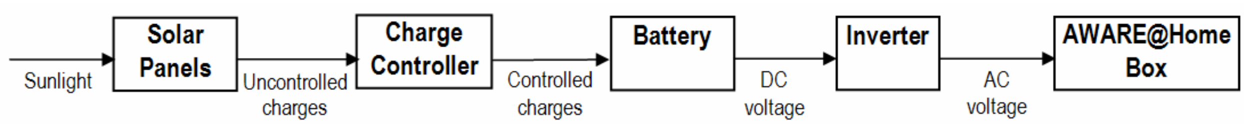
After we weighed the advantages and disadvantages of the various powering options, we decided on using different powering methods for each utility. For gas utilities, we decided to utilize solar power while for water utilities; we decided to utilize flow power.

Selected Concept for Gas Meter – Solar Power

For our gas consumption monitoring system, we decided to use solar power. To harness solar energy, photovoltaic (PV) cells are used. Each PV cell (also known as a solar panel) is usually made of two types of silicon, silicon mixed with phosphorous and silicon mixed with boron. The two different types of silicon create an electric field when hit by sunlight. We would like to capture as much sunlight energy as we can in each solar panel; however, due to the restrictions in the design of solar panels, each solar panel can only absorb about 15% of the sun's energy. [6]

For us to be able to use solar power to power the AWARE@Home system, we needed more than just solar panels. Figure 5 shows how the sunlight energy gets converted to AC voltage. Sunlight is absorbed by the solar panels and the uncontrolled charges in the solar panels are put through a charge controller so that the proper amount of charge is sent to the battery. The battery uses the controlled charges to create DC voltage which is sent to the inverter. The inverter then converts the DC voltage from the battery into AC voltage, which is what is present in an electrical outlet in your house.

Figure 5: Conversion of Sunlight Energy to Normal AC Voltage



Our preliminary calculations showed that we needed about 3 Watts to power each of the monitoring AWARE@Home boxes. These calculations were based on the power consumption of the microcontroller and DPAC, the two components that require the most power, and estimation for power consumption of the other devices. The microcontroller operated at 5 Volts (at 60 mA), thereby requiring 0.3 Watts, and the wireless DPAC required about 2 Watts to operate. Solar power could be used for the electricity and gas monitoring systems, both of which are very similar to each other. To determine how many solar cells would be necessary to power the system, we had to find out where the home was located because of the different levels of sunlight present at different locations. There are charts available that list the solar insolation (sunlight intensity) in different cities. For East Lansing, Michigan, for example, the high value was listed at 4.71 kilowatt-hours per square meter per day, the low value was listed at 2.70 kilowatt-hours per square meter per day, and the average value was listed at 4.00 kilowatt-hours per square meter per day. Therefore, knowing where the house was located allowed us to reference its solar insulation value and use that value in the power calculations. In our calculations, we determined that it was best to use the low value because it would more properly ensure that the system can be powered year-round and not just during the summer. [8]

We determined that a 12 volt battery should be sufficient because we didn't anticipate the solar panels needing to be too far from the AWARE@Home box. If the distance between the AWARE@Home box and the solar panels was greater than 75 feet, then we thought we would want to use a 24 volt battery. [7] For sake of calculation, if we assumed that the solar panels would be no more than 45 feet away from the AWARE@Home box, we determined that we could use #14 gauge two conductor copper wire from the solar panels to the battery. This also assumed that the current going through the wire would not exceed one amp and that the voltage drop in the wire between the solar panels and battery would not exceed 2%. Tables on the internet and in books helped us decide what wires to use for varying distances and currents. [9] We worked through some preliminary calculations to get a ballpark estimate of what our solar power system would look like.

Our preliminary calculations showed that each monitoring system would consume 7.5 amp hours per day (high end estimate). This value for amp hours per day assumed that the inverter DC input voltage was 12 volts and also included a correction factor for inverter loss and battery efficiency. From there, we used the average sun hours per day in the area to determine that the total solar array amps required was 3.33 Amps. Next, we needed to determine how big the battery in our system needed to be. To determine the battery size, we needed to know the maximum number of continuous cloudy days expected in the area. We found out that the number we picked for the maximum number of continuously cloudy days greatly altered the battery size needed to power the AWARE@Home system. For example, at the low end of the spectrum, if we chose ten days as our maximum number of continuous cloudy days in the area, the optimum battery size was 150 amp-hours. If we chose 30 days as our maximum number of continuous cloudy days in the area, the optimum battery size was 450 amp-hours. However, if at the high spectrum we chose 60 days as our maximum number of continuous cloudy days in the area, the optimum battery size jumped to 900 amp-hours. The differences in the sizes of these batteries were significant to the cost and size of the overall system.

Based on our preliminary calculations, we knew that we needed to figure out before we are able to implement this solar power design. Obtaining a reasonable approximation of the maximum number of continuous cloudy days was crucial, as it would significantly change the size of the battery needed in our system. Another important issue was trying to find out if there was a way to reduce the number of solar modules that were in our system. The solar panels used in the preliminary calculations ran at $37.00 each, so six panels would have cost $222.00, which would significantly affect whether or not the AWARE@Home system could be used prevalently in American homes, since the upfront cost of the system would be considered high by most consumers. Overall, however, the concept looked as though it would work to power the AWARE@Home system.

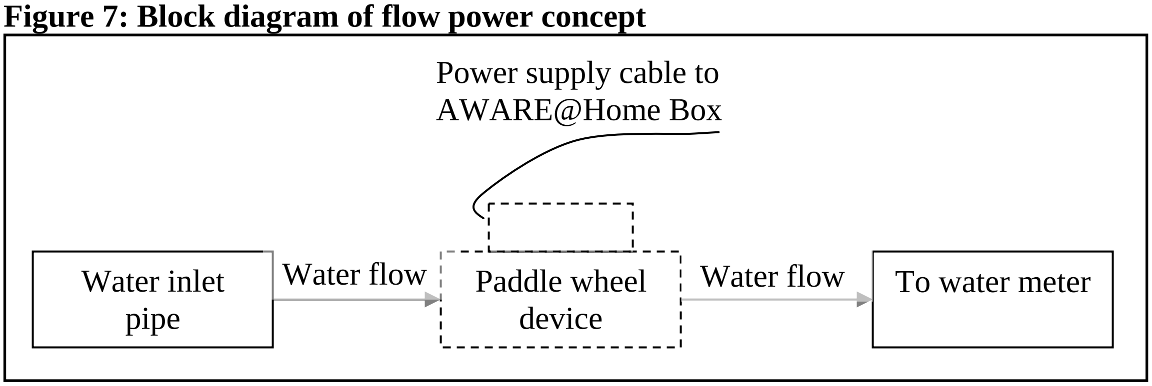
Selected Concept for Water Meter – Flow Power

For our water system, we decided to implement a paddle wheel system. The paddle wheel system would be made by modifying a water flowmeter. If we ran water through a flowmeter, AC voltage could be generated by using a coil that was attached to the spinning paddle wheel. An example of this type of flowmeter is shown in Figure 6. The company with the photo of the flowmeter of interested (http://www.blue-white.com) sells flowmeters that can fit a range of pipe sizes (3/8” to 2”), are optimized to a variety of flow rates (4-200 gallons per minute), and have either female or male threading to attach the flowmeter in line with the water inlet pipe. Our investigations showed that these devices produced an AC voltage of 0.06 V to 3 V depending on the water flow rate. Although at the time we were not sure what the current produced by these meters was, we expected that the current, along with the output voltage, would produce sufficient power for the water monitoring system.

We determined that we did not need to monitor the flow rate of water through the inlet pipe. Therefore, we thought that we would disconnect this feature from the flowmeter and send all of the generated power to the water AWARE@Home box when the system was connected. A block diagram of the proposed flow power concept we proposed is provided in Figure 7.

Figure 6: Sample model of paddle wheel device to be installed in line with water inlet pipe [11]

Figure 7: Block diagram of flow power concept



Engineering Design Parameter Analysis

In the following paragraphs we will be detailing specific parameters used to determine what engineering specifications need to be met for the power supplies of the AWARE@Home boxes.

Solar Panels

The following three sets of calculations were made to design the solar powering system: (1) Average amp-hours consumed by the AWARE@Home system per day (for each individual monitoring box), (2) Total required solar array amps, and (3) Optimum battery size. The detailed calculations can be found in APPENDIX B: Solar Panel Calculations and Corresponding Specifications. Each set of calculations is explained in further detail below.

Average Amp-Hours Consumed: To determine the average amp-hours consumed by the AWARE@Home system per day, we looked at the power consumption of the main components inside the AWARE@Home box, the DPAC wireless transmitter and the microcontroller. The DPAC wireless transmitter was estimated to consume 2 W of power and the microcontroller was estimated to consume 0.3 W of power. We estimated the other components to consume no more than 0.7 W of power. We are in the process of trying to get a more concrete number for the amount of power the AWARE@Home box consumes; however, for now, we are estimating that the system consumes a total of 3 W of power. Using this 3 W estimate and assuming that the system will be running 24 hours a day, 7 days a week, we found that the system would use 504 watt-hours per week. Accounting for a 25% loss in battery efficiency and current consumed by the inverter, the total amp-hours use per week was determined to be 52.5 amp-hours, or 7.5 amp-hours per day.

Total Required Solar Array Amps: To determine the total required solar array amps, we used the total amp-hours per day value from our previous calculation. We accounted for a 20% loss from battery charge and discharge by multiplying the total number of amp-hours used per day by 1.2. Using a solar insulation chart (many charts exist on the Internet), we found that the closest city (East Lansing, MI) on the chart gets a high of 4.71 sun hours per day, a low of 2.70 sun hours per day, and an average of 4.00 sun hours per day. [8] To be safe, we used the low value of 2.70 sun hours per day in our calculation. From these values, we determined that 3.33 solar array amps are required to power the AWARE@Home box.

Optimum Battery Size: To determine the optimum battery size, we used the total amp-hours per day value from our previous calculations. An important estimation to determine battery size is the maximum number of continuously cloudy days that is expected in the area where the system is going to be installed. We have assumed that the Ann Arbor, MI area has a maximum of ten continuously cloudy days (the calculations in APPENDIX B also contain the calculations using a maximum of 30 continuously cloudy days). Because batteries don't operate as well at lower temperatures, a factor of 1.59 was used to account for the cold winter temperatures in Michigan. From these values, we determined that our optimum battery size is 150 amp-hours if a maximum of ten continuously cloudy days is used and the optimum battery size increases to 448 amp-hours if a maximum of 30 continuously cloudy days is used. For our prototype, we will assume the 150 amp-hour battery size is adequate for our purposes.

<u>Paddle Wheel Power</u>

The engineering issues that needed to be considered for the paddle wheel device were: (1) Geometry of water inlet pipe, (2) Flow rate of water coming into residential homes, (3) Contamination from paddle wheel housing material, and (4) Amount of power produced. All of these issues were investigated before the decision was made to order a paddle wheel to power our water monitoring system.

Geometry of Water Inlet Pipe

The size of the water inlet pipe at Professor Skerlos' house was measured to be 7/8". Blue-White Industries, Inc., the manufacturer of the paddle wheel we have ordered, has paddle wheels integrated into in-line pipes at a diameter of 1" that can easily be attached via a reducer to the inlet pipe.

We consulted with the technical experts at Blue-White Industries regarding the flow rate of water that comes into homes. We were informed that the range of flow-rates for their 1" in-line pipe paddle wheel flowmeter, 0.8-8 gallons per minute (gpm) will more than cover the high end flow rate of water coming into the house. The minimum flow rate of 0.8 gpm that produces power from the paddle wheel may be slightly higher than the water inlet flow rate for such uses as turning on a kitchen or bathroom sink. However, many other household water uses such as operating a dishwasher, washing machine, shower, or toilet, will provide a flow rate between 0.8-8 gpm that will provide power from the spinning paddle wheel.

The pipe that houses the paddle wheel needs to be made of a material that doesn't corrode and contaminate the water that's coming into the house. The in-line pipe paddle wheels made by Blue-White Industries are available in two materials: Polypropylene or PVDF (Kynar). Both of these plastics are safe for use with residential water. The PVDF model is designed to resist corrosive chemicals and is more expensive than the polypropylene model. Since we are only interested in the transport of water through the paddle wheel assembly, we selected the Polypropylene housing model.

Our intended use of the paddle wheel flowmeters is novel. The device that we've ordered from Blue-White Industries is traditionally used to monitor the flow rate of a fluid that is passing through. The read-out of the flow rate is given on an LCD screen that needs a power source. The paddle wheel is inside the flowmeter in order to generate power when fluid passes through the device. The paddle wheel is connected to a coil sensor that senses the fluid flow rate and generates AC voltage when the paddle wheel spins. The AC voltage generated by fluid flowing through the device is 0.06 V to 3 V. We will use this voltage, which generally powers a digital flowmeter readout device, to charge a rechargeable battery that will power the microcontroller and other components inside the AWARE@Home box. The paddle wheel flowmeter has wires coming out from the coil that we will connect to a rectifier to transform the voltage into the amount needed to recharge the battery we will be using. This information is provided in the Prototype Description section of this report.

After consideration of the engineering issues associated with using a paddle wheel flowmeter to power our water monitoring system, we have found it to be a viable solution and will be implementing it in our prototype.

PROTOTYPE DESCRIPTION

In the following paragraphs we will be detailing specifications of the individual components of our prototype. We will begin by discussing design for manufacturability and failure/safety considerations. Then we will describe the details of the natural gas and water consumption monitoring units. Lastly, we will give a brief overview of the prototype software.

Design for Manufacturability

Our project is intended to create a product that can be mass-produced and used in households worldwide. However, we created a single prototype system for our project that is not readily suitable for mass manufacturing for several reasons that include: (1) the components for our system come from many different suppliers throughout the US, (2) for safety and legal reasons our prototype requires a second meter for each utility at the homes it would be installed at, (3) the AWARE@Home enclosures are larger than necessary, (4) powering for the system includes exposed batteries and loose (but insulated) wiring that should be concealed, (5) the complete prototype system for natural gas and water monitoring costs about $2500 which is too expensive for common household use. In addition, the cost of the prototype electricity monitoring system is about $700.

As we designed and built our prototype, we were mindful of how costs could be reduced and how the other issues addressed above could be resolved in order to mass produce the AWARE@Home system. It will still be necessary to order parts from different manufacturers but knowing all these manufacturers ahead of time and having a working relationship with them will allow for faster shipping and delivery. Cost can be greatly reduced by using less capable microcontrollers and wireless serial bridges, less powerful solar arrays, and using only one meter for each type of utility monitoring. Space can be saved by enlarging the AWARE@Home box to be able to store all the power components or reducing the size of the current box and using a second enclosure to store the power components.

Our prototype was over designed which helped us to meet circuitry, powering, and space requirements. For mass manufacturing, our prototype would use the same structure and concepts but have fewer components that are scaled down if possible.

Failure/Safety

We used a program called DesignSafe 3.0 to analyze the safety issues associated with our prototype design. The following types of personnel will likely be needed for installation and maintenance/repair of household AWARE@Home systems: maintenance technician, electrician/controls technician, materials handler, and installer. The risks posed to AWARE@Home units and these people come from the tasks that they perform which include trouble-shooting, installing/repairing circuitry and electronics, delivering materials, testing, and training customers.

A number of possible risks were generated from the DesignSafe risk analysis package but none of these risks posed more than an occasional and low-level threat. The principal risks posed to personnel come from electronics and circuitry of the system. There can be exposed wires, ungrounded wires, short circuits, wetness on electronic surfaces, electrostatic discharge, and sparks. There are also some lesser risks from a mechanical standpoint that include cutting of wires and precisely inserting wires into the circuit board which can cause pinching. Additionally, the instillation of a powering unit close to the flow of natural gas poses the risk of explosion.

In order to best avoid these risks, the following should be done before any power is supplied to the system: all powering systems and circuitry should be properly grounded, the wires should be properly insulated, electronic surfaces should be wiped dry of any wetness, and workers should not wear clothing that might conduct static electricity near the components. Wires should be cut carefully and pliers with plastic coated handles should be used to install wiring into the circuit boards. Additionally, work should not be done on the system outside when there is a chance of lightning. A fire could start from the powering cords being hit.

The homeowner that uses the AWARE@Home system does not face any hazardous risks since they interact with the system through their home computer. In fact they can reduce the risks associated with power outages by using the system since utility companies will be informed faster of the outage and be able to correct it sooner.

Natural Gas Consumption

The natural gas prototype is very similar to the previously detailed electricity monitoring unit. However, it does have its differences and those differences will be detailed in the paragraphs of this section.

RIOTronics

As previously mentioned, a RIOTronics pulse sensor has been chosen for our natural gas consumption prototype. It will be used to send consumption information to a microcontroller within the AWARE@Home box. From the microcontroller, a wireless 802.11b network is used to send the information out wirelessly to a base computer. At this point, the computer uses software to calculate consumption usage and populate visuals referencing this usage. This coding then allows for an echo of consumption information to be sent to DTE/MichCon.

The RIOTronics sensor has been professionally installed onto a working natural gas meter. The sensor will be attached to the AWARE@Home box so that the microcontroller will be able to collect and send out the required information. This will be done using weatherproof wiring and will enter a weatherproof NEMA enclosure that will hold the components of the AWARE@Home box.

NEMA Enclosure

A NEMA enclosure has been selected for our prototype to keep the components of the AWARE@Home box dry, satisfy safety issues, and to be able to mount the components next to the meter, located outdoors.

The enclosure includes a brass plate that allows for an easy install or attachment of the components. A simple 6/32 inch drill and tap will allow for a screw down installation. As shown in Figure A9, the interior design of the enclosure is also set up with four 110 Volt outlets. These outlets are used to support the power supplies necessary for the individual components. The entire box is going to be connected to a power supply that will provide power to each of the 110 V outlets.

Another critical issue that the NEMA enclosure provides is a lock and latch feature as shown in Figure A10. Due to the fact that this box will be placed outdoors in a local neighborhood, there is always a safety hazard with little children. We do not want anyone to get hurt as a result of our product. With a lock and latch feature, we can avoid unexpected or unwanted tampering of the components.

Lastly, the box will allow for an easy install onto the side of a residential house. The box will screw into the brick, siding, or stone using the appropriate hardware tooling. The enclosure is relatively light and can be mounted with four screws.

An assembled prototype of the enclosure and its components can be seen in Figure A11. Each of the components has a picture that is more clearly shown in Figure A12-Figure A15: LCD/Keypad, Microcontroller, and the wireless 802.11b network.

Installation: Series Connection with Current Residential Meter

As mentioned, the RIOTronics sensor has been professionally installed onto a working natural gas meter. This gas meter will need to be tested and calibrated. Once completed, this meter will need to be installed in series with a currently installed residential natural gas meter. This will allow us to do some testing without tampering with the current meter and allow us to take better safety based steps.

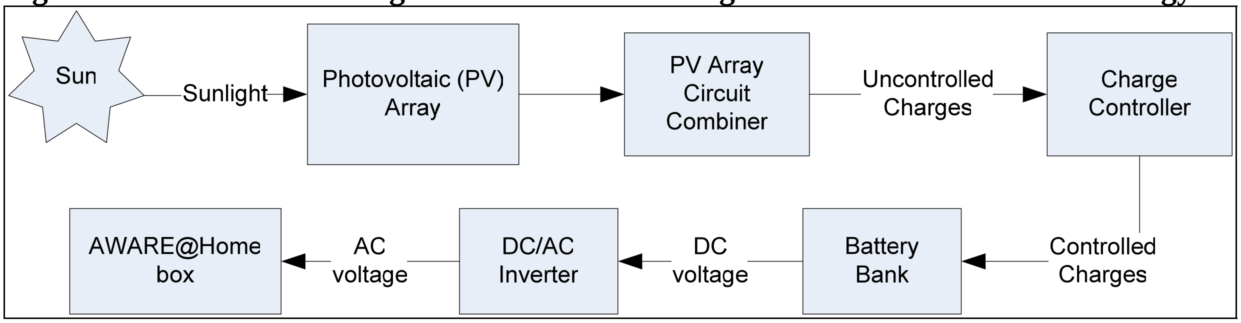
Power Supply: Solar Panels

We have designed a solar powering system for the AWARE@Home box assuming power consumption of 3 W. In the first part of this section, “Overview,” we will outline the main components of the solar powering system design and the functions of these main components. Following this, in the “Detailed Design Description,” we will explain what main components we have picked for the prototype. We will also show the sizes of the components in the Prototype Sizing section to provide a good idea of how big the entire system will be. Also, we will provide explain how the components of that make up the system work together and provide a preliminary bill-of-materials (BOM).

Overview:

The main components of the solar powering system for natural gas are: (1) photovoltaic (PV) array, (2) charge controller, (3) battery, and (4) DC/AC inverter. A schematic is shown in Figure 8 showing how sunlight is converted to usable power for the AWARE@Home box.

Figure 8: Flow chart showing the basics of how sunlight is converted into usable energy



Photovoltaic (PV) Array: The purpose of each solar module is to convert light (i.e. photons) into electricity. The PV array then pumps current into the battery through a charge controller (see the next section below for further explanation).

Charge Controller: The purpose of the charge controller is to block reverse current from the battery and to prevent the battery from overcharging. It is important to prevent the battery from overcharging because if energy is being continuously supplied to the battery when it is at full charge, the voltage of the battery gets too high, creating the risk of a small explosion. The charge controller ensures that, when the battery reaches a particular voltage, the amount of energy being sent to the battery is reduced.

Battery Bank: The purpose of the battery/battery bank is to store the energy from the PV array for days when there is little or no sunlight to power the AWARE@Home box. For solar powering systems, the best choice is a deep-cycle battery. Deep-cycle batteries are made to be discharged and re-charged many times and are capable of discharging more of the energy stored in the battery than in other types of batteries. The batteries used in solar powering systems discharge less current over a longer period of time as opposed to batteries such as a car battery, which discharge a very large current over a very short period of time (when you start your car). [12]

DC/AC Inverter: The purpose of the DC/AC inverter is to convert the 12 VDC power from the battery into 115 VAC power that can be used by the AWARE@Home box.

Detailed Design Description:
Having completed our engineering design parameter analysis and research, we have selected the main components of our solar powering system. A description of each of these components is outlined below.

Photovoltaic (PV) Array: The PV array in our system will consist of two solar modules. For our prototype, we will be using the ThinFilm Series solar panels manufactured and sold by Silicon Solar. The particular model used in the prototype (Item number: 04-1086) has an open circuit voltage of 16-18 volts and a short circuit current of 1800-2000 mA. As described in the “Engineering Design Parameter Analysis” section for solar power, we need approximately 3.4 solar array amps for our solar powering system; hence, we need two solar panels to be able to create the necessary amount of power need to power the AWARE@Home box. Additional specifications for the solar panels we have chosen are outlined in APPENDIX B.

Charge Controller: The charge controller we have chosen for our prototype is the Brunton SolarController. The SolarController is capable of handling up to seven amps of array input and 100 watts of power from the solar panels. This should be more than adequate for the PV array we have chosen, since the array will likely create no more than four amps of current. The selection of this charge controller gives some room for modification, at the same cost of another charge controller with less capability. Additional specifications for the charge controller we have chosen are outlined in APPENDIX B.

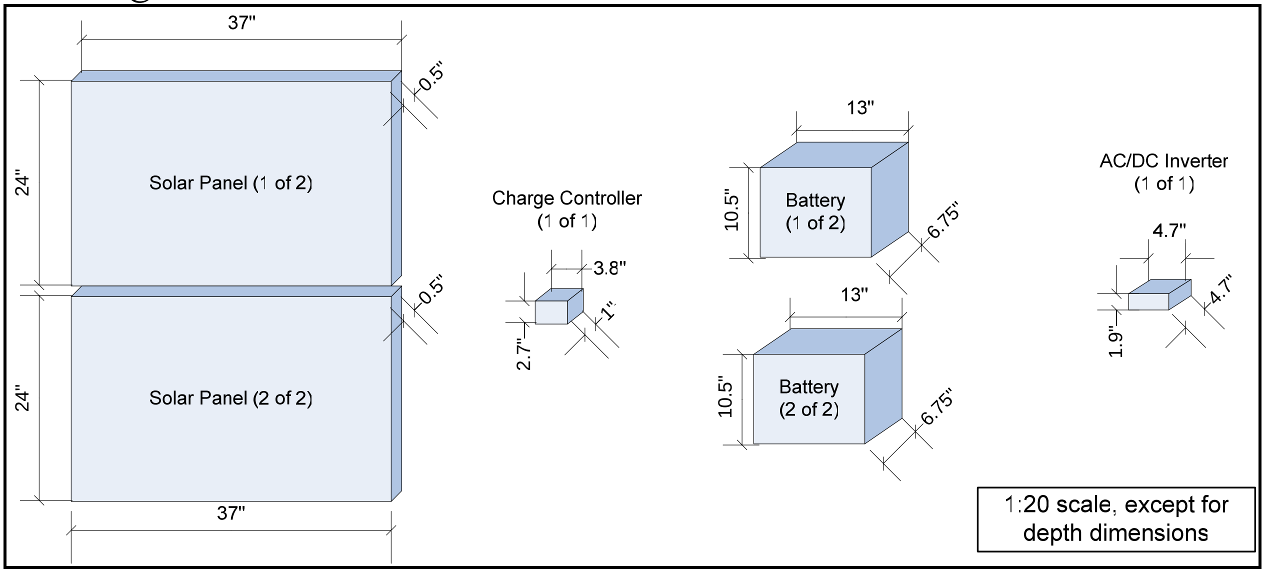
Battery Bank: The battery bank will consist of two batteries. For our prototype, we have chosen the 12 volt AGM battery manufactured by Universal Battery and supplied by Creative Energy Technologies. Each battery has an amp hour capacity (20 hour rate) of 110. As described in the "Engineering Design Parameter Analysis" section for solar power, we calculated that we needed a battery size of approximately 150 amp-hours if the maximum number of continuously cloudy days in the area is 10 days. The number of batteries and size of each battery in the battery bank will vary by location. For our particular location, we have assumed that the maximum number of cloudy days is 10 days. Therefore, we need two of the batteries described above to be able to power the system during cloudy days. Additional specifications for the batteries we have chosen are outlined in APPENDIX B.

DC/AC Inverter: For our prototype, we chose a modified sine wave inverter. Modified sine wave inverters approximate a sine wave. Although true/pure sine wave inverters are available, they are more expensive than the modified sine wave inverters. We have chosen the Xantrex PROWatt 150 Modified Sine Wave Inverter supplied by Infinigi. This inverter powers AC products up to 150 watts.

Prototype Sizing:

Using the dimensions provided by suppliers/manufacturers, we created Figure 9 to give a ballpark estimate of the size of the entire design as described above. Wires will connect most of the components – measurements of the house the system's going to be installed on are needed to actually lay out the system.

Figure 9: Dimensions of the Main Components of the Solar Powering System for the AWARE@Home box

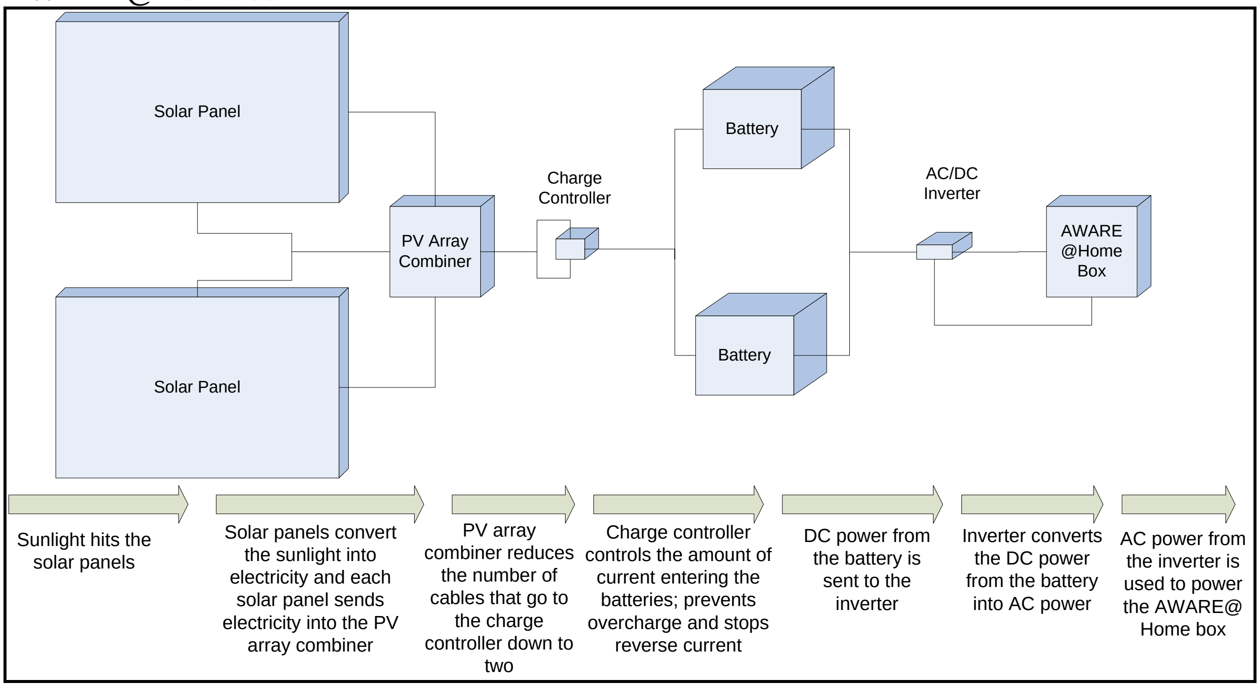


One thing that should be kept in mind is that the power usage by the AWARE@Home box was estimated to be 3 W (in our first calculation of amp-hours consumed per day). This is a very important estimation/assumption because this changes all the values that reference this number, and, hence, changes the system requirements. The number of solar panels in the PV array and number and size of batteries in the battery bank could very likely decrease if the power consumed by the AWARE@Home box is reduced. One idea for decreasing the power consumption in the AWARE@Home box is to only turn the components you need on when you need them, and not have them run continuously. If no consumption is being detected, the system could go into somewhat of a sleep mode awakened by the pulsing of new consumption. Another option may be to design the system to have "low power mode" when it is only running certain tasks. Reducing the power consumption of the system is not our goal here – it is to develop an outline of how we designed our particular system to actually work. Also, by laying out the calculations and functions of each main component, it is our hope that those working on this project in the future can re-design or modify the system without much difficulty.

Operation of the Prototype:

The components we have chosen will be put together to form the solar powering system. Figure 10 shows how the different components interact with each other to power the AWARE@Home box. First, sunlight hits the solar panels, which consist of many photovoltaic (PV) cells made of silicon. The solar panels thus convert the sunlight directly into electricity. The electricity from each solar panel then goes into the PV array circuit combiner, which reduces the number of cables that have to go into the charge controller to two. The combined electricity from the solar panels then goes through a charge controller and into the battery. The charge controller regulates the amount of charge the battery gets, preventing the battery from becoming overcharged. If a battery is overcharged, there is a chance that it may cause an explosion. Another function of the charge controller is to block reverse current. Batteries store DC power, which cannot be used directly by the AWARE@Home box. Therefore, the DC power from the battery bank has to go into an AC/DC power inverter. The power inverter takes the DC power and converts it to AC power. The AWARE@Home box can plug directly into the power inverter and use the power that has just been created by the sun.

Figure 10: **Summary of how the solar powering system design works to power the AWARE@Home box**



Bill of Materials:

The bill of materials in Table 3 shows the different parts that make up the solar powering system. The main components are listed in the table with a supplier, manufacturer, and cost.

Table 3: Bill of Materials for the Solar Powering System

Supplier	Part #	Quantity	Manufacturer	Description	Cost/unit
Silicon Solar	04-1086	2	Silicon Solar	ThinFilm Series Solar Panel	$ 179.95
Creative Energy Technologies	UB121100	2	Universal Battery	UB121100	$ 154.25
Infinigi		1	Xantrex	PROWatt 150 Modified Sine Wave Inverter	$ 33.28

Water Consumption

The water consumption monitoring unit again is very similar to the previously detailed utility monitoring units. The specific characteristics have been detailed in the following paragraphs of this section.

Hall Sensors

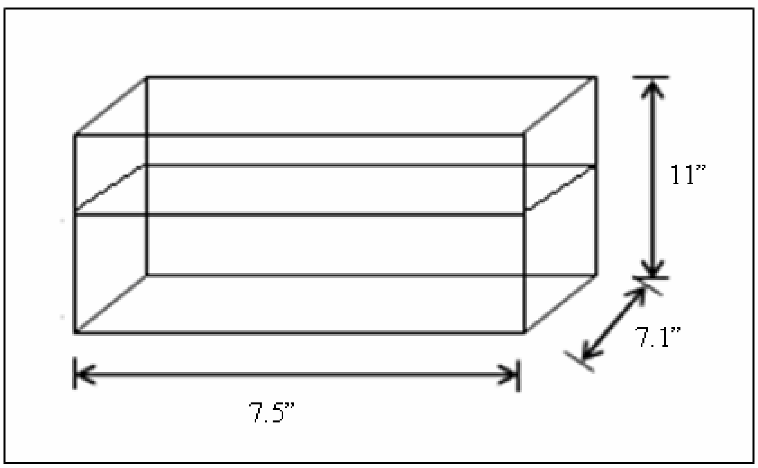
As previously mentioned, a hall sensor will be used as the pulse sensor for our water consumption prototype. It will be used to send consumption information to a microcontroller within the AWARE@Home box. From the microcontroller, a wireless 802.11b network is used to send the information out wirelessly to a base computer. At this point, the computer uses software to calculate consumption usage and populate visuals referencing this usage. This coding then allows for an echo of consumption information to be sent to DTE/MichCon.

The hall sensor will be installed onto a working water meter. The sensor will need to be attached to the AWARE@Home box so that the microcontroller will be able to collect and send out the required information. This will be done using wiring and will enter an enclosure that will hold the components of the AWARE@Home box.

Enclosure

Similar to the natural gas AWARE@Home box, we used a NEMA enclosure to house the water AWARE@Home box. The dimensions of this box are shown in Figure 11.

Figure 11: **Dimensions of NEMA enclosure for water monitoring**

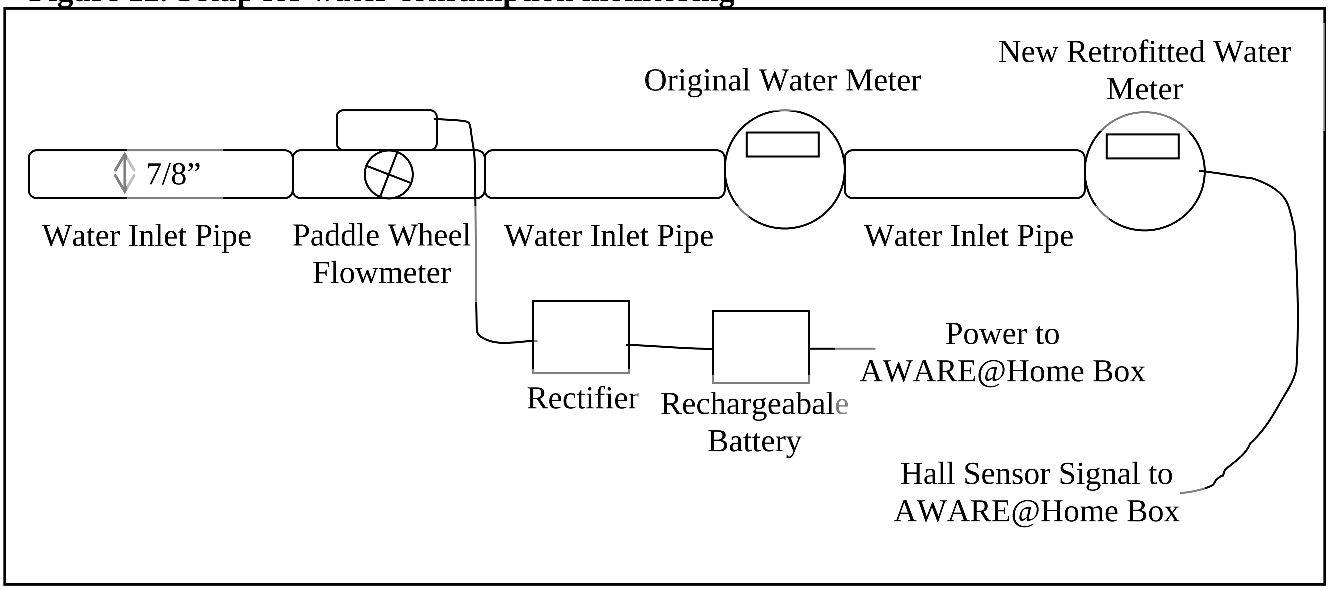


Power Supply: Paddle Wheel Flowmeter

For water consumption monitoring, a second water meter will be installed next to the meter already present at Professor Skerlos' house. The water inlet pipe will need to be cut open for this installation process. In addition to the second water meter, we will also be installing a paddle wheel flowmeter in line with the water inlet pipe so that the water coming into the house flows through this device before reaching the two water meters. The housing for the flowmeter is a polypropylene 3/8" pipe that will fit in-line with the water inlet pipe at Professor Skerlos' house. The max operating temperature of the unit is 200° F (93° C) and the max operating pressure is 300 psi gauge (20 bar).

Once the system is in place, as water flows through the inlet pipe, it will cause the paddle wheel to spin. For the operating range of 0.8-8 gpm of water flow, the paddle wheel will generate 0.06-3 V of AC voltage through a coil sensor to which it's attached. The wires from the coil will be connected to a rectifier to transform the voltage into the correct amount needed to recharge a battery that will be attached. This battery will be sufficient to provide the 3 W of power needed for the microcontroller and other components inside the water AWARE@Home box. We have decided to use a 12 volt battery and a bridge rectifier composed of four diodes. Figure 12 details the water consumption monitoring system.

Figure 12: **Setup for water consumption monitoring**



Software (User Interface)

The final software prototype will be what was described in Visual Basic Coding, Selected Concept Description Section. There will be no differences between what was discussed in that section, and what will actually be done in prototyping. However, in order to make the system fully operational, the DPAC Wireless Serial Links must be configured correctly to ensure the usage information sent out from each utilities microcontroller reaches the Visual Basic Coding.

DPAC Wireless Serial Link Configuration

To ensure that information flows correctly from each utilities microcontroller to the Visual Basic software the DPAC Wireless Serial Link had to be configured. The DPAC Wireless Serial Link inside of the water AWARE@Home box has been logged into and configured correctly. The baud rate has been changed from 9600 rate to 115200 and a static IP has been set to 192.162.0.3. Additionally, the desired com port has been set to 7 for water using VCOM Configuration Utility – 1.0.0. In order to ensure the flow of information for the gas utility, similar settings will need to be made for the DPAC Wireless Serial Link corresponding to gas.

FINAL DESIGN AND PROTOTYPE COMPARISON

In the following paragraphs, we will compare similarities and differences between our prototype and proposed final design. Some places where the prototype system could improve include: (1) including the solar powering system for the gas monitoring unit, (2) avoiding use of a second utility meter, and (3) implementing a shut-off valve into the gas inlet pipe to cut off supply to non-paying customers.

Natural Gas Consumption

The following paragraphs detail some changes and improvements we would recommend to our prototype system for use in the final design.

NEMA Enclosure: Aesthetics

Ideally, in a final design implementation, DTE/MichCon would team up with a company who would be able to mass produce the necessary electrical components for the AWARE@Home monitoring systems. If or when this happens, our group is under the assumption that the partnered company will also be able to decrease the size of the components. With a decrease in size of the components within the NEMA enclosure, the overall size of the enclosure can be adjusted accordingly. This will allow the unit to appear more aesthetically pleasing outside of a home and would also likely decrease the cost of the system because less material would be used.

Retrofitted Residential Meter: Installation

In the final system design, we do not expect that the retrofitted meter will be connected in series with the current residential meter. Instead, the pulse sensors would likely be directly retrofitted, hopefully onsite, into the current meter. Putting two meters in series would cost a utility company a lot of money in purchasing or making new meters. Thus, we feel that current utility meters can be easily retrofitted to work with the AWARE@Home system.

Natural Gas Monitoring Power Supply: Fuel Cells

Ideally, we would like to use a fuel cell as the power supply for the natural gas AWARE@Home box. A fuel cell is an electrochemical energy conversion device which would separate hydrogen and oxygen out of the natural gas. Once the hydrogen and oxygen are separated, the fuel cell would convert it water while simultaneously producing electricity. Fuel cells produce direct current (DC) voltage that can be used to directly power the AWARE@Home box. One of the great advantages of using fuel cells with the natural gas AWARE@Home system would be that since natural gas would constantly be flowing, the AWARE@Home system could be constantly powered. Fuel cells would also require little to no maintenance, which would save natural gas companies like MichCon a lot of money on maintenance calls, especially when compared to a solar panel which we are predicting will need routine maintenance.

The technology for fuel cells is still very much in progress and hence is also very expensive. From our research, we could not find a fuel cell small enough to serve the needs of the AWARE@Home box. Thus, we are hoping that in the future the technology will be such that we can use fuel cells for our purposes. [13]

Shut-off Valve Implementation

Recently, MichCon informed us of a major concern that they have with regard to natural gas – the stealing of natural gas. The stealing has been attributed to piping around the meter or tampering with the meter. Therefore, they would like to see an automated or remote valve incorporated into the natural gas monitoring system that would allow MichCon to turn off a house’s natural gas if they are not paying for it. Unfortunately, we were not informed about this concern until late into our project when we had already begun prototyping. Due to time constraints, we decided that we did not have ample time to do extensive research into the topic, as we needed to concentrate our efforts on getting the natural gas and water consumption monitoring systems to a working state. Thus, we have decided that the implementation of a remote natural gas shutoff valve will be a challenge for future AWARE@Home project teams to face.

Water Consumption

The final design for the water AWARE@Home box and paddle wheel powering system will be very similar to the prototype we have designed this semester. The paddle wheel flowmeter will be used to recharge a battery that will power the microcontroller and other components inside the water AWARE@Home box for the final design. However, instead of connecting an additional water meter in series with the meter already present at the user's home, we recommend retrofitting the existing meter with a hall sensor. This avoids the cost of a second meter, saves space, and is more aesthetically pleasing. Retrofitting the existing meter with a hall sensor would need to be done by a professional to ensure that the hall sensor is properly installed since the water meter is the property of the local water utility company.

The other change we recommend from the water consumption monitoring prototype to the final design is using a paddle wheel that provides sufficient recharging power to the battery that is used to power the water AWARE@Home box. The paddle wheel we ordered provides 10-500 µA (AC) and 0.06 – 3 V (AC), which is not enough to charge the 12 V battery we used. A three-step solution to this problem is to: (1) attach more magnets to the paddle wheel to generate more current and voltage, (2) modify the diode rectifier circuit by including a booster, transformer, or other circuit components that increase voltage or current, and (3) use a battery with less voltage.

To successfully follow the steps for the above solution, more calculations need to be performed to determine what battery size is needed to power the water AWARE@Home box. Additionally, calculations need to be performed to calculate the minimum amount of voltage and current needed to charge the chosen battery. We recommend that these calculations be performed by an expert in electrical engineering who has experience with powering systems.

Software

The prototype that was constructed for software is a good image of what the final software will look like from the user's perspective, with a few major differences in how data the data will flow. One potentially large difference between the prototype and final design is the way in which information is sent to DTE. Currently, data is routed through a local computer and sent via the internet to DTE. In the final design, it is desired that information not be routed through a local computer, rather that the information be directly sent to DTE. Many discussions of changing the way information is transmitted to DTE have been discussed, however, one method has not been chosen.

To eliminate having to route information through a local computer, the function that posts XML strings to DTE inside of the current Visual Basic code will need to be transferred inside of the AWARE@Home box. This change would alter the general concept of the Diagnostic Panel in the Visual Basic software. This panel would either be eliminated from the program or its function would drastically change. Additionally, this new function inside of the AWARE@Home box would call for some software updates, which still have to be addressed.

The next step in the data flow process would be to decide how to pick up information from the AWARE@Home system and route it to DTE. Some of the most appealing final design concepts are communication using broadband over power lines or wireless transmission through cellular towers. If broadband over power lines is used, receivers would be installed on telephone poles similarly to the way that transformers are. These receivers would be responsible for their own areas, and would be responsible for receiving incoming data and relaying it to DTE. Similarly, in the event that cellular towers are used, information would bounce off the cell phone towers and would be relayed to DTE. Both of these concepts are plausible; however, a final decision has not been made as to the best option for our application.

Since the final design eliminates the passing of information through the homeowner's computer, CSV files will no longer be needed. Instead, software on the user's home computers will log directly onto DTE's server and access utility consumption information.

MANUFACTURING PLAN

The following paragraphs outline how several parts of the AWARE@Home system were manufactured. We have also included a list of project expenditures in this section.

Electronic Component Assembly

Once we received the parts we needed, we assembled the electronic components for both the water and natural gas consumption monitoring prototype units. The components listed in the bill of materials in Figure A27 have been provided in this section for your convenience as Table 4. Please note that the value found in parentheses in the "Quantity" column is the number of each unit that is found in a single monitoring AWARE@Home box, if applicable.

Table 4: **Project Expenditures**

Part Number	Part Name	Distributor	Quantity	Total Cost
ABDB-SE-DP101	Wireless Serial Link	DPAC	2 (1)	$ 460.00
CML-912SDP256	Microcontroller	AXIOM	2 (1)	$ 232.00
HC-LCD	LCD Display	AXIOM	2 (1)	$ 64.00
HC-KP	Keypad	AXIOM	2 (1)	$ 46.00
NB141207-100	NEMA Enclosure (Gas Only)	Hyperlink	1 (1)	$ 179.00
ASR-PG13	G-13.5 Conduit Connector (used in NEMA Enclosure)	Hyperlink	1 (1)	$ 3.95
ASR-PG16	PG-16 Conduit Connector (used in NEMA Enclosure)	Hyperlink	1 (1)	$ 3.95
69945 K999	Weatherproof Enclosure (Water Only)	Mcmaster-Carr	1(1)	$ 77.90
N/A	Circular Read Nat. Gas Meter	EEI	1	$ 75.00
TPIN2-2P	RIOTronics PulsePoint (1 ft^3)	RIOTronics	1 (1)	$ 43.00
DS1305	Maxim Time Chip	Digikey	4 (1)	$ 20.24
SS441A	Honeywell Hall Sensor (Water Only)	Digikey	4 (1)	$ 8.60
CFS-32.768KDZB-UB	Time Chip Crystal	Digikey	4 (1)	$ 1.12

N/A	100 Ohm Resistor	N/A	2 (1)	$ 0.00
N/A	1000 Ohm Resistor	N/A	2 (1)	$ 0.00
N/A	47,000 Ohm Resistor	N/A	2 (1)	$ 0.00
N/A	PNP Transistor	N/A	2 (1)	$ 0.00
EEC – S0HD104V	0.1F 5.5V Capacitor	Digikey	4 (1)	$ 7.92
FCXX10M2	Paddle Wheel Flowmeter Coil Sensor, 1" pipe	Blue-White Industries	1 (1)	$ 290.30
04-1086	ThinFilm Series Solar Panel (Gas Only)	Silicon Solar	2 (2)	$ 359.90
ETX12	12 V AGM Battery (Water Only)	Extreme Magna Power	1(1)	$ 52.99
UB121100	Universal Battery (Gas Only)	Creative Energy Technologies	2 (2)	$ 308.48
Xantrex	PROWatt 150 Modified Sine Wave Inverter	Infinigi	2 (1)	$ 66.56
DX-UBDB9	USB to serial adapter	Dynex	1	$ 35.99
TOTAL				$ 2336.90

The first step we took was to create the breadboard on the Microcontroller as seen in Figure A13. This was accomplished using the necessary resistors, transistors, capacitors, LCDs, time chips, and wiring as assigned by a previous electronically focused AWARE@Home project team.

Next, we connected the Microcontroller up to the LCD screen, keypad, and wireless network. These components were once again chosen by the previous AWARE@Home project team and have been proven effective in the electricity monitoring unit.

Finally, we needed to secure the components down to the individual NEMA enclosures for the natural gas monitoring and the water monitoring units. The NEMA enclosures were ordered online and detailed information regarding the purchase can be found in the Project Expenditures Table, Table 4.

Natural Gas Enclosure

The NEMA enclosure purchased for the natural gas monitoring unit needed to be weatherproof and the specific model we found online had a brass mounting plate. Installing the components within this enclosure was very simple and straightforward. The microcontroller and wireless network had mounting holes for a screw down assembly while the NEMA enclosure had a brass board that allowed for easy tapping for mounting of the microcontroller. Locations for each component were chosen strategically to allow for maximum space. Once the locations for each component were determined, a 6/32 inch drill and tap were used to create a mounting location on the brass board of the enclosure. Then, using screws, the components were mounted as shown in Figure A11.

Installing the keypad and LCD screen required a little more work than simply screwing down the components. The issue that arose was that both the keypad and LCD screen had to face upwards. Since the electrical circuitry was all located on the bottom side of the LCD screen, it could not be screwed down because the brass board would cause or act as a short on the board. Thus, we created a Plexiglas mounting board that was mounted at an elevated level above the brass board using threaded brass rods, nuts, and washers. The dimensions of the Plexiglas mounting board can be found in Figure A15 and a real life picture of the final result can be found in Figure A12

Water Enclosure

The enclosure purchased for the water monitoring unit did not necessarily have to be weatherproof since the enclosure would be kept indoors near the water meter. The specific model we purchased from Mcmaster-Carr did not have a mounting plate within the enclosure. Because we did not have a mounting plate within the enclosure, we were forced to create our own mounting plate. We created the plate out of Plexiglas using a laser cutter and designed it so that it could be affixed onto the bottom of the enclosure with epoxy. The plate was designed with 7/32 inch holes that allowed us to mount it with 6/32 inch screws and washers. A detailed layout of the design can be seen in Figure A16. Although this mounting plate design was not very difficult, in the future we would recommend that a brass mounting plate be used in both enclosures to allow for easier installation.

Installing the keypad and LCD screen proved to be slightly easier for the water monitoring unit. We once again had to create a Plexiglas mounting board. However, for this unit we did not have to drill and tap the mounting board nor did we have to use threaded rods, nuts, and washers to elevate the board. Instead, we created the board with the exact dimensions of the internal walls of the enclosure such that the Plexiglas could rest on a lip located at the top of the enclosure. The dimensions and design of the Plexiglas mounting board can be seen in Figure A17.

Solar Panels

We did not manufacture the components in our solar powering system. Instead, we purchased all the components from various solar power suppliers (see Table 3 on page 34). We did, however, design and built a mobile cart that allows for easy transportation of the solar panels so that we can more easily show off our prototype and place all the solar powering components in one place for validation purposes. The cart was built using lumber and was designed to hold all four of the solar panels such that the face and are parallel to the ceiling, ensuring that light can more easily be absorbed by the panels. Rough dimensions of the cart lumber pieces that we made the solar cart out of can be seen in Figure A18. Upon building, minor alterations were made to the dimensions to provide better stability of the cart and panels.

Due to time constraints, we unfortunately will not be able to install the solar powering system prototype onto a house. If the solar powering system is installed on a house, a mounting frame would be necessary to hold the panels properly. The mounting frame would have to be securely bolted down to ensure that the frame doesn’t fall over and damage the solar panels. Another option would be to install the solar panels on the roof of a house; however, this probably isn’t the best idea since the solar powering system we’re using is still in the prototype stage.

Paddle Wheel

As is the case with the solar panels, the paddle wheel and necessary components for the prototype were all purchased. For validation purposes, we put together a working system that used plastic piping and many fittings to connect a paddle wheel to a standard household faucet. Since the paddle wheel flowmeter we planned on using for the prototype did not arrive in time for us to validate it, we used a paddle wheel from Professor Skerlos' lab to test the overall system and make sure that the water meter worked properly. In the working prototype, we also took advantage of a valve to help validate our system. The valve was installed at the end of the piping. A detailed picture of the setup can be seen in Figure 15 as well as a detailed validation approach can be detailed on page 46.

Unfortunately, due to time constraints, we will not be able to install the prototype in a house. The paddle wheel flowmeter we ordered will likely require professional installation onto the water inlet pipe at Professor Skerlos' house. This would be done by shutting off the water supply to the house, sawing off a portion of the inlet pipe and then installing the flowmeter in line with the pipe by screwing down the flowmeter at both ends.

VALIDATION AND TESTING

We needed to verify that our system worked before a prototype could be installed at Professor Skerlos' house. The following paragraphs detail how we have shown that our prototype system works properly.

Natural Gas Consumption

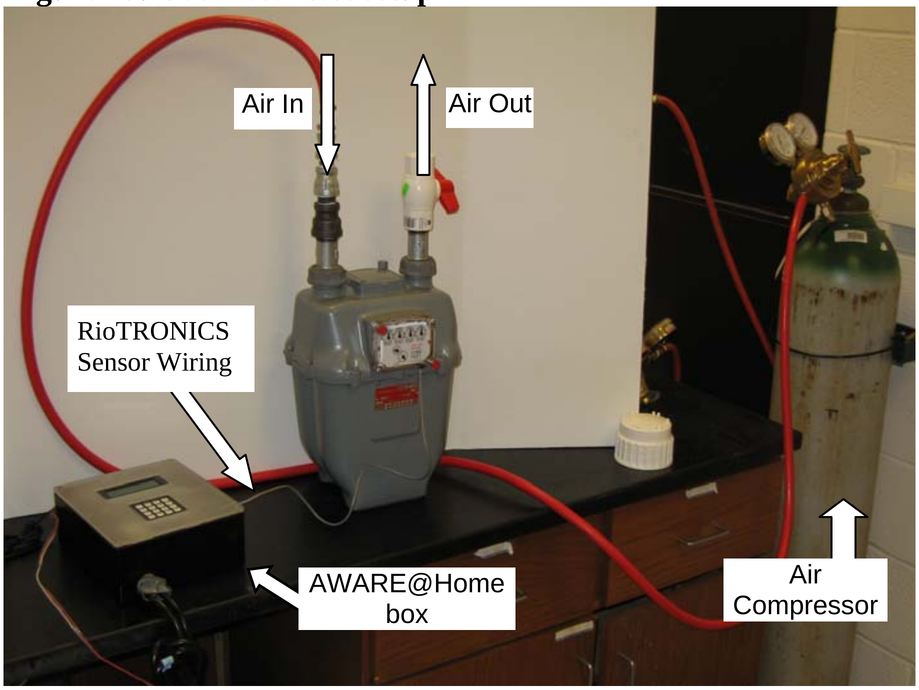
For the natural gas consumption monitoring system, there were two main components we had to validate: the gas meter and the solar powering system. In this section of the report, we will describe the validation approaches we took for both of the components.

Gas Meter

We ordered the natural gas meter from Energy Economics, Inc. which was shipped to RIOTronics Inc., who installed the RIOTronics sensor. The natural gas meter was a refurbished model from EEI that they tested and recalibrated. Even though we expected the meter to be in fine working order when it arrived, we conducted our own tests to ensure that the meter worked properly.

We used an air compressor to flow air through the inlet pipe to the gas meter. The setup for this test is shown in Figure 13. Although this test didn't help us check the accuracy of the meter for natural gas, it did help us to determine that the meter would record gas flowing through it. When compressed air was flowing through the pipes, the dials on the face of the gas meter would spin. At higher pressures, the dials would spin faster, and at lower pressures, the dials would spin slower.

Figure 13: Gas meter test setup



<u>RIOTronics Sensor</u>

Due to shipping difficulties, we had very little time to gain an understanding of the RIOTronics unit and could not find a solution to the implementation of the RIOTronics unit in our system.

The RIOTronics sensor works similarly to the hall sensor in that it sends out a pulse each time a magnet passes by the sensor. However this pulse is not a sharply defined square wave with jumps to high and low values as is the case for a hall sensor. Instead there are some ripples in the output signal as it increases and decreases which could cause extra pulses to be read by the microcontroller. Therefore a debouncing method needs to be integrated into the microcontroller code before pulses are correctly measured from the RIOTronics sensor. In addition, installation into the breadboard is not the same as for the hall sensor.

Debouncing the Microcontroller Code

For debouncing the microcontroller code we knew that the maximum debounce time is 0.2 ms and we tried using a PACTL value of 0X50 (see [22] for a description of this pulse accumulator feature). However, due to our lack of electrical engineering knowledge, we were not able to look in depth into this change and verify its impact on the system.

Breadboard Installation

We were advised to install the three leads of the RIOTronics sensor (positive, negative, and ground) into the same slots used by the hall sensor. However, a resistor must be attached to the negative outlet before the signal is sent to the PC7 lead in order to account for the closed circuitry the sensor appears to follow.

We recommend that the future of this project look into breadboard installation and microcontroller coding in order to successfully validate the RIOTronics sensor.

Solar Powering System

To test the solar powering system, we tested two separate parts of the overall system: (1) the solar panels, and (2) the battery and inverter.

Solar Panels

To test the solar panels we placed a single panel in a given location under the room lights at which point we then connected the panel to a voltmeter and collected a voltage output reading. We then repeated the process for the remaining three panels. We wanted to be sure that each panel read approximately the same value and we found all four panels did read to the same value within a tolerance of 0.25 V.

To test our series connection of the solar panels, we connected the four solar panels together by a soldering method and then connected the panels to a voltmeter and placed the panels in approximately the same location that the individual panels were placed for their validation. We used the voltmeter to see if the reading we received was approximately 4 times the reading we received for the individual panels. According to the information we gathered, the solar panels in series produced an output of 3.2 times the individual panel readings. We felt comfortable with this value considering the different amounts of illumination throughout the room.

We then used the voltmeter to see how the voltage output of the solar panels changed with different amounts of light. In Figure 14(a), with all the room lights on, the solar panels had a voltage output of 9.07 volts. When only half the room lights were on, the voltmeter reading dropped to 2.986 volts, as shown in Figure 14(b). When all the room lights were turned off, the voltmeter reading dropped to 20.0 mV, as shown in Figure 14(c). These output voltage readings further proved validation to us in showing that the solar panels worked.

Figure 14: **Solar panel testing: (a) voltmeter reading with all lights on, (b) voltmeter reading with half the lights on, and (c) voltmeter reading when all lights are off**

(a) (b) (c)

Inverter and Battery

To test the inverter and battery, we connected the positive and negative terminals of the power inverter to the negative and positive terminals of the deep cycle battery, respectively. To test to make sure that the inverter and battery connection was correct, we plugged a fan into the inverter. When we did this, the fan started spinning, which meant that the connection between the inverter and battery was good.

Future Natural Gas Validation

Although we would have liked to have MichCon install the gas meter on Professor Skerlos' house, time constraints did not allow us to do this. When the retrofitted gas meter is installed on Professor Skerlos' house, someone will have to perform a calibration and determine the accuracy of the meter. Ideally, the reading on the retrofitted meter will be within ±5% of the correct measurement in accordance with our engineering target. Another test that will have to be run, once the meter is installed on Professor Skerlos' house, is that his monthly natural gas utility bill will need to be compared with the monthly natural gas charges recorded by the AWARE@Home software. There will be inaccuracies caused by factors such as peak usage rates and changing utility rates, but the effect from these factors should be small enough to determine how well the natural gas monitoring system works.

We weren't able to validate that the solar panels actually charge the battery. To validate this step, one would need to drain the battery down so that the solar panels (placed in lighting) can be connected to it and tested to see if the charge in the battery increases. One obstacle relating to this is finding out how much charge is in the battery. One way that the charge of the battery may be able to be measured would be to use a voltmeter to see how the voltage of the battery changes when it's partially drained. This method has not yet been tested, as we wanted to get confirmation of the safety and electrical issues associated with connecting the solar panels to the battery and inverter before proceeding with this test so that we didn't damage the components or hurt someone.

The RIOTronics sensor has two steps of validation that we couldn't finish due to time constraints: installation on the breadboard and debouncing of the pulsed output signal. These are both open-ended issues at the moment that require significant investigation. Correctly debouncing the output signal probably requires adjusting the PACTL, PACNT, and PAFLG reference values that are used for the pulse accumulation portion of the microcontroller code.

Finally, it is important to validate that the entire natural gas AWARE@Home system works. Therefore, the powering system, retrofitted gas meter, and AWARE@Home box need to be installed on a house to see whether or not the entire system works together. It may be advisable to hire a professional to install everything or at least double check to make sure everything is connected properly.

Water Consumption

For the water consumption monitoring system, there were two main components we had to validate: the water meter and the paddle wheel powering system. In this section of the report, we will describe the validation approaches we took for both of the components.

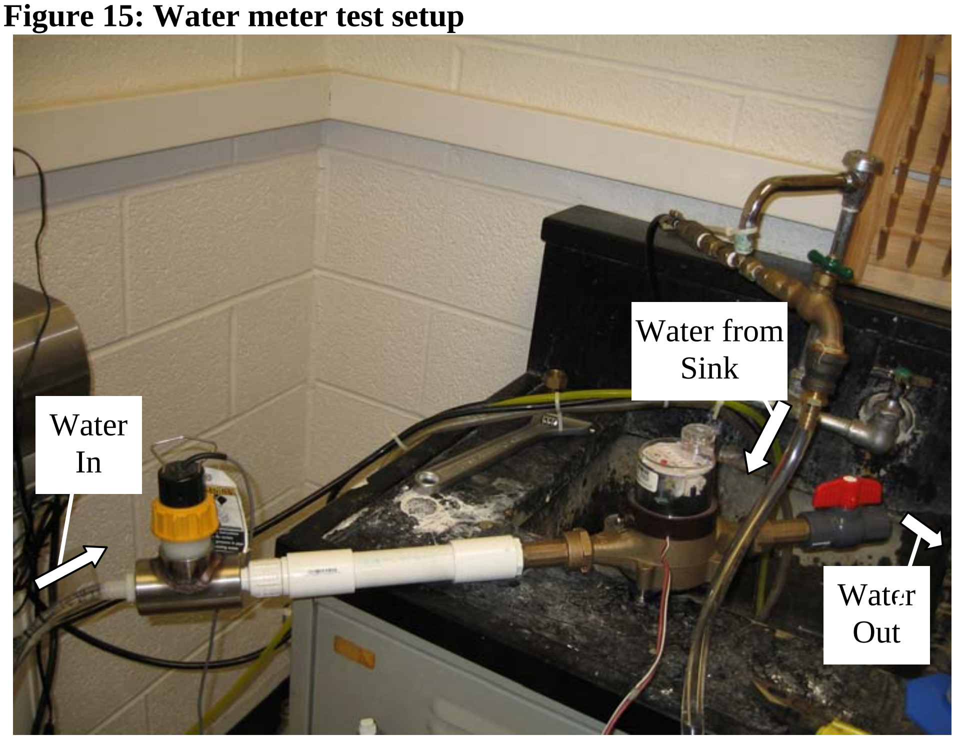
Water Meter

We received a working water meter from the previous ME 450 team that worked on the AWARE@Home project. That team primarily worked on the design for electrical consumption monitoring but had purchased a water meter that they ended up not using for their project. The water meter was in good working order when the previous ME 450 team had it for their project. Even though we expected the meter to still work, we conducted our own tests to ensure the meter worked properly.

We used polypropylene hose attached to a sink (via a hose barb) to flow water through the water meter. We attached PVC piping to the inlet pipe of the water meter. This piping was attached at the other end to a paddle wheel flowmeter. The other end of the flowmeter was attached to a hose barb that connected to the hose from the sink. The setup for this test is shown in Figure 15. Although this test didn't help us check the accuracy of the meter for water, it did help us to determine that the meter would record water flowing through it. When water was flowing through the pipes, the dials on the face of the water meter would spin. At higher pressures, the dials would spin faster, and at lower pressures, the dials would spin slower.

Once we verified that the dials spun, we needed to verify that the dials spun accurately. Therefore, we used a bucket to collect the water that ran through the system. This bucket water was then poured into numerous beakers to measure the amount of volume that was sent through the meter to check for accuracy of the meter reading. Using the volume measurements taken from the beakers, we then added the volumes to find a total volume in liters. This summation was then converted using a conversion factor to find the total volume in cubic feet. We ran the experiment three times and every time the summation of volume collected in the buckets matched the meter reading.

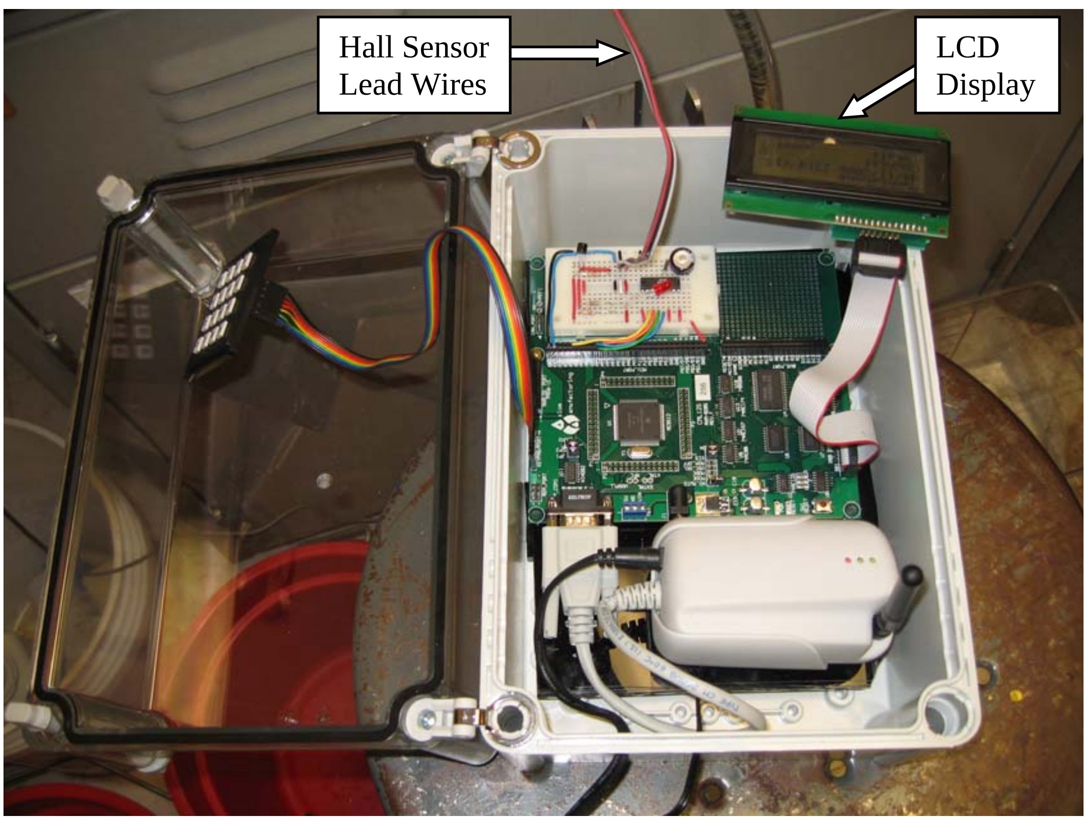
Figure 15: Water meter test setup



Hall Sensor

We first tested that our hall sensor worked by connecting its lead wires to the prototype board inside of the water AWARE@Home box as shown in Figure 16. We then powered the box and swiped a small magnet by the sensor. We observed that each time we swiped the magnet by the sensor, the pulse count on the LCD screen increased by one. This validated that the microcontroller code that accumulated hall sensor pulses worked. We then taped the hall sensor underneath the plastic cap of the water meter and right above the metal base. We observed that as water flowed through the meter, the spinning magnet in the metal base caused the hall sensor to send out a pulse each time the magnet passed it by. The accumulated and new pulses were displayed on the LCD screen. In order to complete the validation of analog to digital data conversion of water consumption data, we counted the number of cubic feet that the water meter advanced for 40 pulses from the hall sensor. We found that the meter recorded 0.09 ft^3 of water passing through it for the 40 pulses sent out. This means that a pulse is sent out for every 0.00225 ft^3 (0.09/40) or equivalently every 0.0168 gallons of water that pass through the meter. After the microcontroller sends out the pulses to the base computer with the AWARE@Home software, the software converts the pulses to gallons using the conversion factor we found in the Visual Basic coding.

Figure 16: Water AWARE@Home box with hall sensor attached



Paddle Wheel Powering System

To determine the voltage and current generated from the paddle wheel flowmeter, we attached an oscilloscope to the lead wires from the coil that is attached to the paddle wheel as shown in Figure 17. The setup for flowing water through the water meter and paddle wheel was the same as shown in Figure 15. The paddle wheel we ordered from Blue-White industries did not arrive in time for our testing so we used a paddle wheel available in the EAST lab in the GG Brown building at the University of Michigan. Unfortunately, this paddle wheel was not the type that generates voltage and current so no readings were observed on the oscilloscope. The exact same procedure would be used for the paddle wheel from Blue-White that does generate voltage and current in order to measure the amplitudes and frequencies of the AC voltage and current.

Figure 17: **Paddle wheel test setup**

Future Water Validation

Although we would have liked to have a plumber or utility company install the water meter on Professor Skerlos' house, time constraints did not allow us to do this. When the retrofitted water meter is installed on Professor Skerlos' house, someone will have to perform a calibration and determine the accuracy of the meter. Ideally, the reading on the retrofitted meter will be within ±5% of the correct measurement in accordance with our engineering target. Once the meter is installed and connected to the AWARE@Home system at Professor Skerlos' house, the monthly water utility bill will be compared with the monthly water charges recorded by the AWARE@Home software. As mentioned previously, there will be discrepancies due to such factors as peak usage rates and changing utility rates but the effect from these factors should be small enough to determine how well the water monitoring system works.

We weren't able to validate that the paddle wheel flow meter actually charges the battery. We know that the output voltage and current from the paddle wheel flow meter is not sufficient to charge the 12 V battery that we had been using with the inverter to power the AWARE@Home box. The first step in this validation process is calculating a minimum battery size that will provide sufficient power to the AWARE@Home box and a minimum voltage and current needed from the paddle wheel to charge this battery. These calculations are best done by an electrical engineering expert who has experience with powering systems. The next step is to drain the battery down so that the paddle wheel can be connected to it and then to test if the charge in the battery increases as water flows through the paddle wheel.

Finally, it is important to validate that the entire water AWARE@Home system works. Therefore, the powering system, retrofitted water meter, and AWARE@Home box would have to be installed on a house to see whether or not the entire system works together. It may be advisable to hire a professional to install everything or at least double check to make sure everything is connected properly.

Software

Before validating our Visual Basic coding, we first needed to validate our microcontroller coding. Having valid microcontroller coding would allow for a properly formatted string of information to be streamed into the Visual Basic coding.

Microcontroller coding

Various methods were used to validate the microcontroller coding. The first method used was the output displayed in AxIDE, the software used to upload coding to the microcontroller. After our coding was uploaded, the microcontroller was set to auto mode and allowed to run while connected to AxIDE. In this configuration, we could see the microcontroller outputs as they stream out ever thirty seconds. Being able to see these outputs allowed us to visually verify our code.

To verify our code in this configuration, we manually swiped a magnet by the Hall Effect Sensor to generate a pulse into the system. We then visually verified that the system read the pulse via the LCD display. Upon hitting the thirty second mark, the microcontroller outputs its stored information. We then viewed this output through AxIDE and visually verified that the system was taking in and outputting information correctly.

A second check used in validating the microcontroller and its DPAC Wireless Serial Link was to log into the Wireless Serial Link and view its output directly.

The validation in this configuration was similar to that described above for our validation of the microcontroller code. We manually swiped a magnet by the Hall Effect Sensor to generate a pulse into the system. This pulse then needed to be confirmed that it was being sent through the DPAC Wireless Serial Link. In connecting to the Wireless Serial Link, we were able to view the output and confirmed the transfer though the DPAC unit.

Visual Basic Coding

The validation of our visual basic coding took place in 4 steps. These steps are outlined in the following paragraphs.

Step 1: Verification of the incoming information is displayed and stored properly

To verify information was being read in and displayed correctly, we utilized each utility's Com Set button from the diagnostics panel and each utility's CSV files. The Com Set panel for each utility allows us to see what information is being read in while the CSV file allows us to see what is being stored. Inside of our software, the function in charge of updating CSV files is called every thirty seconds; this function could have been called through the each utility's Update CSV button. The system is designed to have the Com Set panel for each utility refresh and CSV files updated every thirty seconds. Additionally, each utility's CSV files should log the hourly total counts and a cumulative total.

To validate the system, we connected it to our validated microcontroller. This allowed us to simulate a real world scenario. In this setup, we allowed the system to send in a valid data stream while the pulse count was slowly incremented via the swiping of a magnet over the hall sensor. We could then visually verify the software was reading in the correct information for each utility and updating every thirty seconds via their respective Com Set panels. Next, we manually compared the stored CSV files to what was sent in. We found that these files were updated every thirty seconds and matched what was being sent in. Next, we allowed our system to run over a four hour period while reading in information from the microcontroller as its pulse count was randomly increased. At the end of the four hour period, we verified that the CSV logs for each utility matched what was sent in. The final CSV files used in this validation stage can be seen in Figure A19.

Step 2: Verification that the information is configured in the correct way to be sent to DTE

After verifying the correct reading in and storing of information, it was important to verify that our code could configure information in the correct form, XML string form, to be sent to DTE. To verify that our software could do this, we utilized the Write XML buttons for each utility. Figure A20 shows a sample XML stream. All three systems have been validated to configure XML strings correctly.

Step 3: Verification that information can be sent to DTE correctly

Upon verifying that the software configures XML strings correctly, we needed to verify that the software could send information to DTE. To validate this, we utilized the Send XML buttons of each utility. These buttons call each utility's send XML function inside of the Visual Basic coding respectively. Figure A21 shows a sample xml log file. All three utilities have been validated and are able to send information to DTE.

Step 4: Verification of the correct referencing and plotting of information for all plots and values in the Energy Usage tab

After validating that our system could read in, store, and send out information correctly, we needed to verify that it references its stored data correctly while plotting and calculating spending accurately. To validate these issues, a template CSV file was created. For this CSV file, all costing information and utility usage was calculated. These calculated values were then referenced against what was displayed in the Energy Usage panel of the Visual Basic Coding. All displayed values matched their calculated values. This final stage completed our Visual Basic validation.

INFORMATION SOURCES

Our team has been in contact with numerous sales representatives from different companies in order to prepare for the implementation of our natural gas and water consumption monitoring systems. Human interaction has been one of our most reliable sources for gathering the information we need to proceed with our project. However, when dealing with sales representatives from companies we try to look out for trickery or deceitful sales techniques. Thus, we try to double check the information we obtain from sales representatives through other sources to ensure its validity.

Coding

In an effort to come up to speed on the existing coding, we asked John Pariseau for help. In casual meetings, John introduced us to the Visual Basic package. He showed us how to interact with the current software as a user would. Later, in a two hour information session, John gave us a basic overview of the existing code and explained how it made everything possible. Finally, John presented us with a strategy on how to implement the necessary changes that would make our software goals a reality.

Natural Gas Meter

To install and implement any prototype of our project, we needed a working gas meter to test and install components on. We contacted Energy Economics Inc (EEI), a company that specializes in repairing and remanufacturing utility meters, regarding our inquiry. In particular, we talked with a gentleman named Jim Lovig who was very useful in helping us purchase a meter. Once we gave Jim a background of our research project, he even began to help us in ways outside of selling us a meter. He gave us a few website addresses to look at where we would be able to get a more detailed background of natural gas consumption. One very useful article was found on the US Department of Energy’s website [2] where we have found information regarding averages of daily, weekly, monthly, and annual residential natural gas consumption. He also helped us look at the inlet pressure for the natural gas meter by working us through the Boyles-Charles gas laws.

RIOTronics

Jim Lovig and EEI were recommended to us by Andrew Brock and the RIOTronics Corporation. We first contacted RIOTronics when we were told that their PulsePoint sensor may suit our needs better than our current hall sensor setup. After placing many phone calls and doing a lot of research, we have found that RIOTronics does indeed have advantages.

Mr. Brock gave us a few contacts and website addresses of people who have been in charge of projects very similar to ours. One contact is Kevin Little from Madison, WI. His company's web address is www.iecodesign.com. Mr. Little was in charge of overseeing a project based on residential housing energy efficiency. Another contact is Little Birch. Mr. Birch's company address is www.horizontech.com. Mr. Birch has worked with his company and the Canadian Center for Housing Technology

LA Times

Professor Skerlos informed us of a newspaper article from the LA Times that contains a brief description of a project very similar to ours implemented throughout a county in California (Santa Clarita Valley). The article describes how this county has adopted a system in which consumption information is gathered and sent to the internet where homeowners and the utility companies alike can view the consumption throughout the month. It describes the reason the project was setup was because of the rolling electrical blackout problems that occur throughout the state. The county is hoping that with this system implemented they will be able to prevent or possibly eliminate blackout problems. [14]

TIME CONSTRAINTS

Unfortunately, we were unable to complete every project goal we set to achieve in the beginning of the semester. A couple of unexpected time constraints put this project on hold for unexpectedly long periods of time. One major issue that arose in our project was contributed by shipping difficulties. Another major issue that arose was our lack of knowledge of power supplies and the complexity of a power supply install.

Shipping Delays

Unfortunately, we purchased a gas meter from Energy Economics Inc. (EEI) and shipped it over to RIOTronics for them to install a sensor. After the install, the meter with the installed sensor was sent out to be delivered to our team. However, in the process the mail carrier appeared to have lost our package. Therefore we were forced to reorder both the meter and the sensor install from the two companies. In all the process should have taken a maximum of two weeks. However with the delays, the ordering process took a little over four weeks to complete and left us with very little time to complete tasks before the end of the semester.

Power Supply Delays

The power supply solutions for natural gas and water consumption monitoring have proved to be major design issues for this project. It was difficult to decide on the powering method for each of these utilities due to our inexperience, lack of knowledge of electrical engineering, and the uncommon use of power supplies for our particular application.

Many companies we have consulted with have been unsure of how to guide us to complete our project since we are not using their products for their traditional applications. For example, the paddle wheel we are using is intended to power a display for fluid flow rate that passes through the pipe housing. Instead we will be using the power generated by the spinning wheel to power the water AWARE@Home box.

SUGGESTED FUTURE PROTOTYPE PLANS

Unfortunately due to the previously mentioned time constraints, we were not able to complete every portion of our project that we initially set to complete. However, we do feel that throughout the semester we have completed a great amount and are very proud of ourselves. The following paragraphs detail some of the components of this project that we feel would be beneficial for future AWARE@Home teams to further analyze.

RIOTronics Installation

Due to shipping difficulties, we had very little time to gain an understanding of the RIOTronics unit. We met with a few individuals, including our sponsor John Pariseau, near the end of the semester to try and find a quick solution to the implementation of the RIOTronics unit into our system. Unfortunately, we were not able to draw any conclusions quick enough to finalize the natural gas prototype. The system is complete except for the microcontroller component. Two issues arise with the microcontroller: installation of the sensor into the breadboard and coding alterations to debounce the signal.

We were suggested to install the three leads (positive, negative, and ground) of the RIOTronics sensor into the same slots that the hall sensor would use. However, before sending the negative outlet over to the PC7 lead it must transfer through a resistor to account for the closed circuitry the sensor appears to follow.

We had to debounce the microcontroller code used for the hall sensor to account for the new RIOTronics sensor. We know that the maximum debounce factor is 0.2 ms. In an effort to debounce the RIOTronics signal we used a PACTL value of 0X50. Due to our lack of electrical engineering knowledge and time constraints we were not able to thoroughly look in depth this change and verify the impact it had on the system.

We would like to recommend that the future of this project look into the breadboard installation and microcontroller coding to finalize the prototype for natural gas.

Automobile Diagnostic and Fuel Consumption Monitoring

An automobile fuel consumption monitoring system would enable the vehicle owner to track their fuel consumption through a computer interface. Many vehicles nowadays offer the option for the driver to view his/her fuel consumption inside the vehicle; however, this system does not let the vehicle owner track his/her fuel usage. With a fuel consumption monitoring system, the vehicle owner may be able to set a target spending limit on gasoline and if on track to surpass this limit, can find ways to reduce their gasoline usage.

Unfortunately due to time constraints, we were not able to do more on this portion of the project except for create a few concept generations, as detailed in the following paragraphs.

One of the primary problems of this task is finding a way to share information with a home computer while the car is turned off. If a method of communication is established between the vehicle and the home computer, another obstacle for the monitoring system is ensuring that the data transmission is secure. Not all cars are outfitted with the necessary equipment to precisely measure the amount of gas left in the tank. This makes it difficult to estimate the mileage per gallon the car is getting. The future of this prototype will need to investigate how accurate fuel measurements are for current cars and evaluate whether a more accurate measuring system is needed.

Also the price of fuel varies often so it is more difficult to obtain an accurate estimate of the price of gasoline per gallon. Perhaps the user can input the zip code in which they live and the average gasoline price can be obtained from the internet and used in the AWARE@Home software. Another possible way the software could receive the price per gallon would be a direct user input of the price they paid at their last fill-up. The software could detect when a user has gone to the gas station to get gas and then automatically ask the user for the price paid per gallon.

CONCLUSIONS AND RECOMMENDATIONS

The main goal of the AWARE@Home project is to better preserve the environment. Homeowners benefit from using the AWARE@Home system by reducing utility expenses and utility providers benefit from the system by improved public image and improved repair and maintenance efficiency from the digitization of the utility consumption data. With an AWARE@Home system installed, consumers will be able to easily track their electricity, natural gas, and water consumption and receive alerts when they are on pace to spend more than their desired monthly amount on these utilities. When these alerts occur, the user will be offered tips on how to reduce their utility consumption. The AWARE@Home software will have settings for both beginner and advanced level users.

The expanded AWARE@Home system will not only monitor electricity usage but will also monitor natural gas and water consumption. Due to time constraints we were unable to expand the system to include automobile diagnostics and fuel consumption. The expanded monitoring systems have been prototype and validated; however, due to time constraints, we were not able to install them on a house. Although the expanded system shows improvement over the current system, possible improvements include: (1) the integration of temperature sensors that would automatically control the temperature based on user inputs of a low and high temperature threshold (“comfort zone”) inside the house, (2) allowing for more user inputs for the AWARE@Home program and making the graphical user interface more user-friendly with separate menus for beginner and advanced level users, and (3) adding water quality testing to the water consumption monitoring system.

Important customer requirements for DTE Energy Co. include: improve public image, reduce consumers' use of peak load power, monitor power quality, and optimize repair efforts. Important customer requirements for homeowners include: reduce monthly utility bills, outdoor components of system are weatherproof, system is inexpensive, and software is easy to install and work with. Important customer requirements for both DTE and homeowners are: positively impact the environment, system is reliable and accurate, system can be used during power outage, and current meters are compatible with system.

ACKNOWLEDGEMENTS

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Brent Gillespie, University of Michigan Mechanical Engineering Professor
John Pariseau, University of Michigan Mechanical Engineering BSE student
Andres Clarens, University of Michigan Mechanical Engineering PhD student

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APPENDIX

Appendix A: Figures

Figure A1: Diagnostics Panel

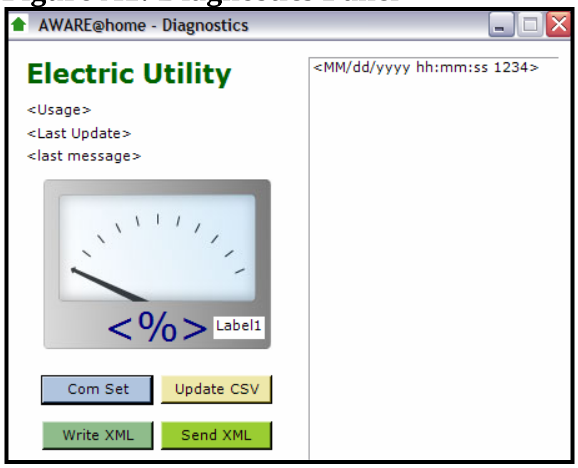


Figure A2: Com Set Panel

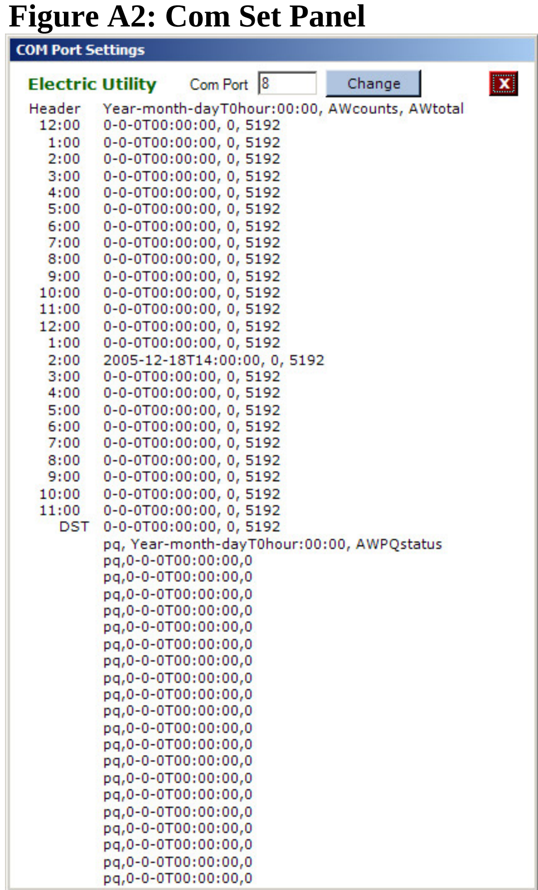


Figure A3: Home Configuration

Figure A4: Preferences

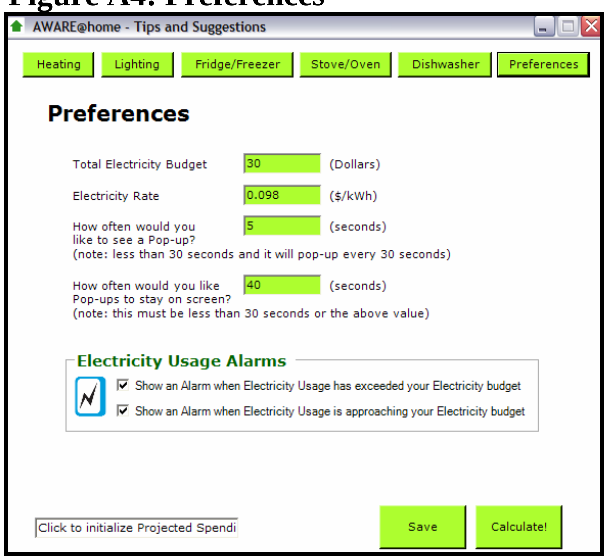


Figure A5: Budget Overview

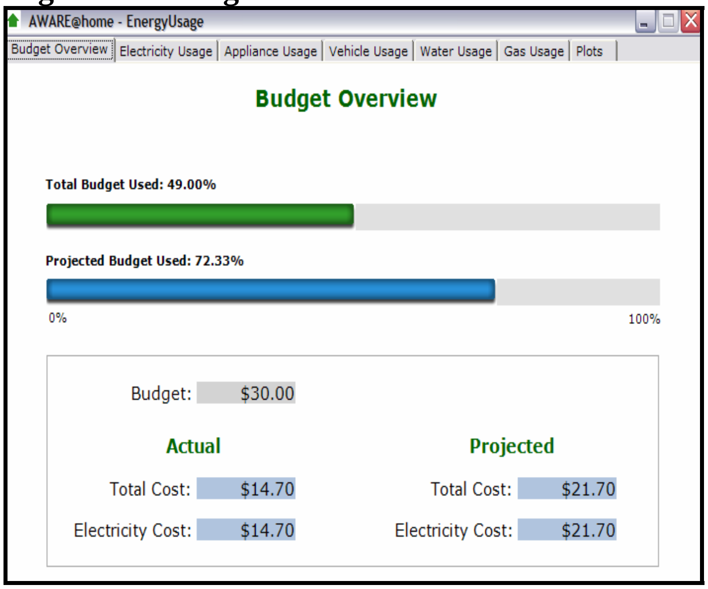


Figure A6: Electricity Usage

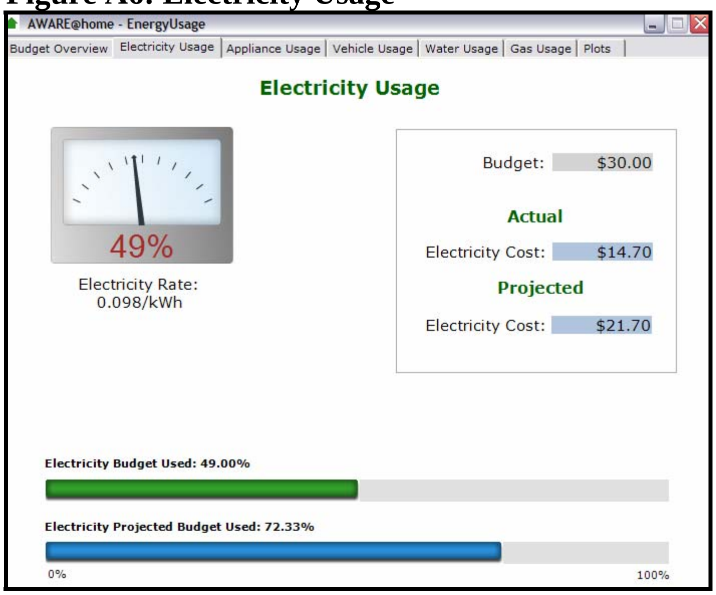


Figure A7: Plots-Cost per Day

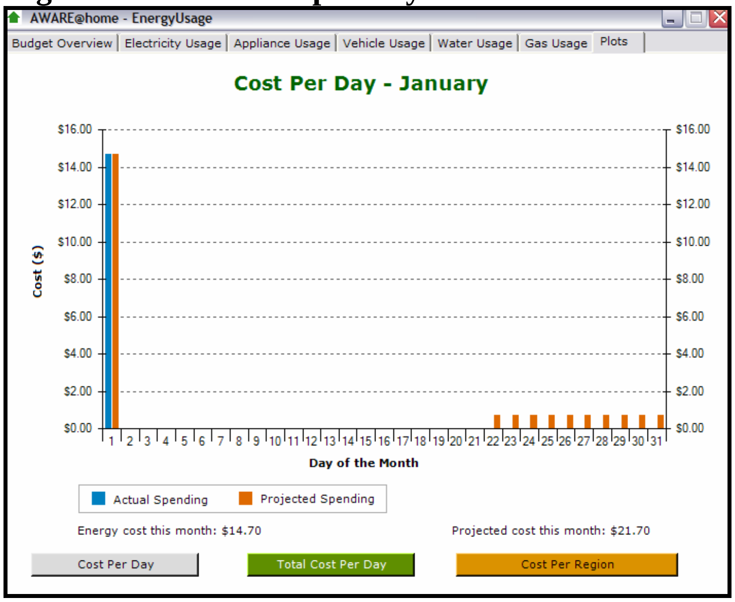


Figure A8: Plots-Total Cost per Day

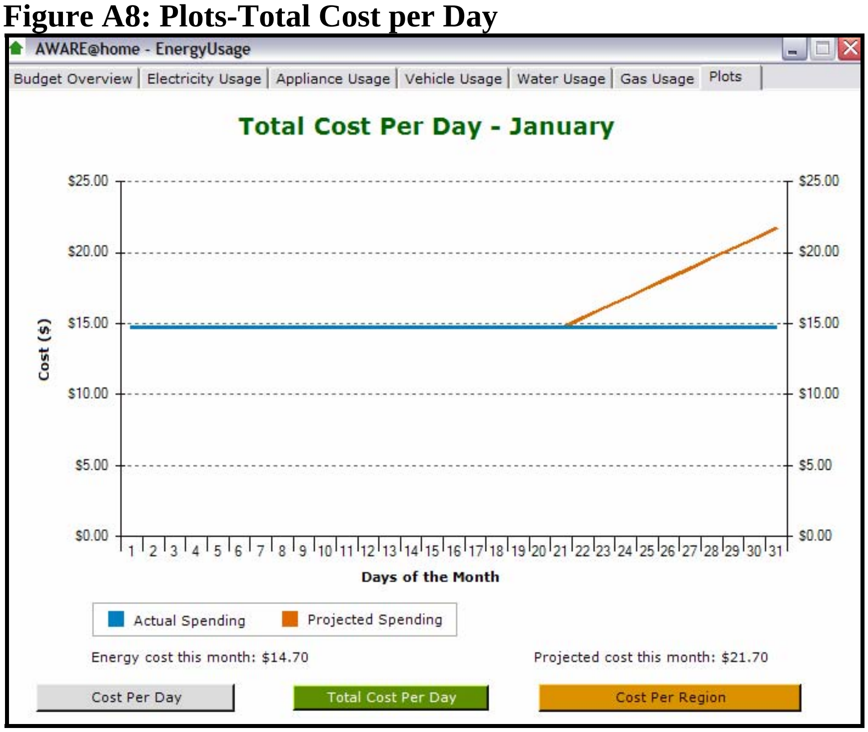


Figure A9: NEMA Enclosure Schematic

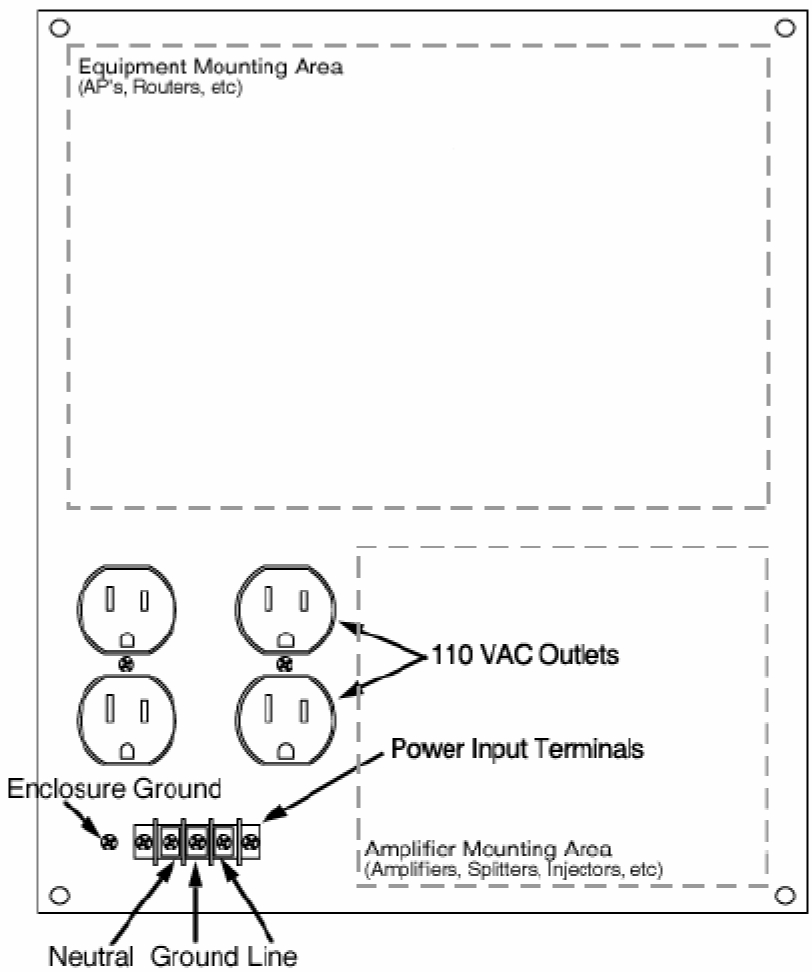


Figure A10: NEMA Enclosure – External

Figure A11: NEMA Enclosure – Internal

Figure A12: AWARE@Home Box Components – LCD/Keypad

Figure A13: AWARE@Home Box Components – Microcontroller

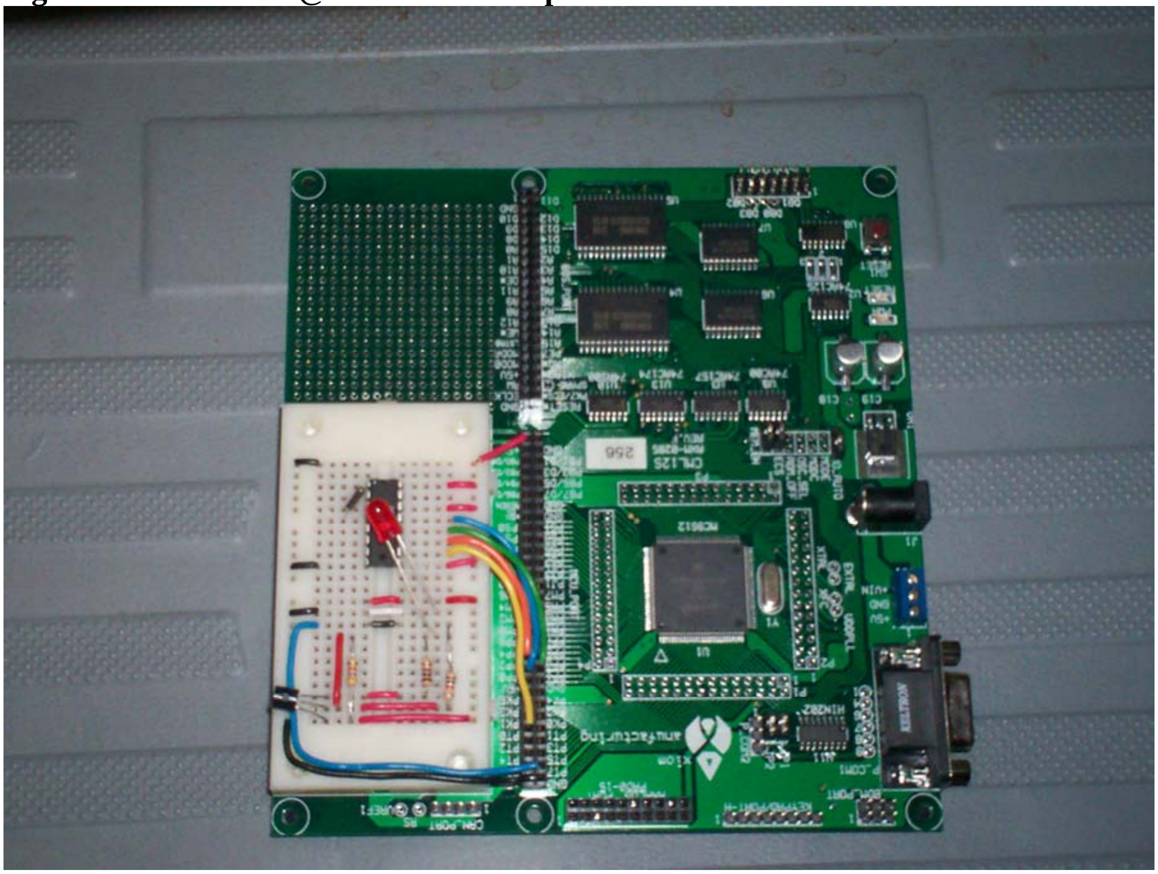


Figure A14: AWARE@Home Box Components – 802.11b

Figure A15: Natural Gas LCD/Keypad – Plexiglas Mounting Board Dimensions

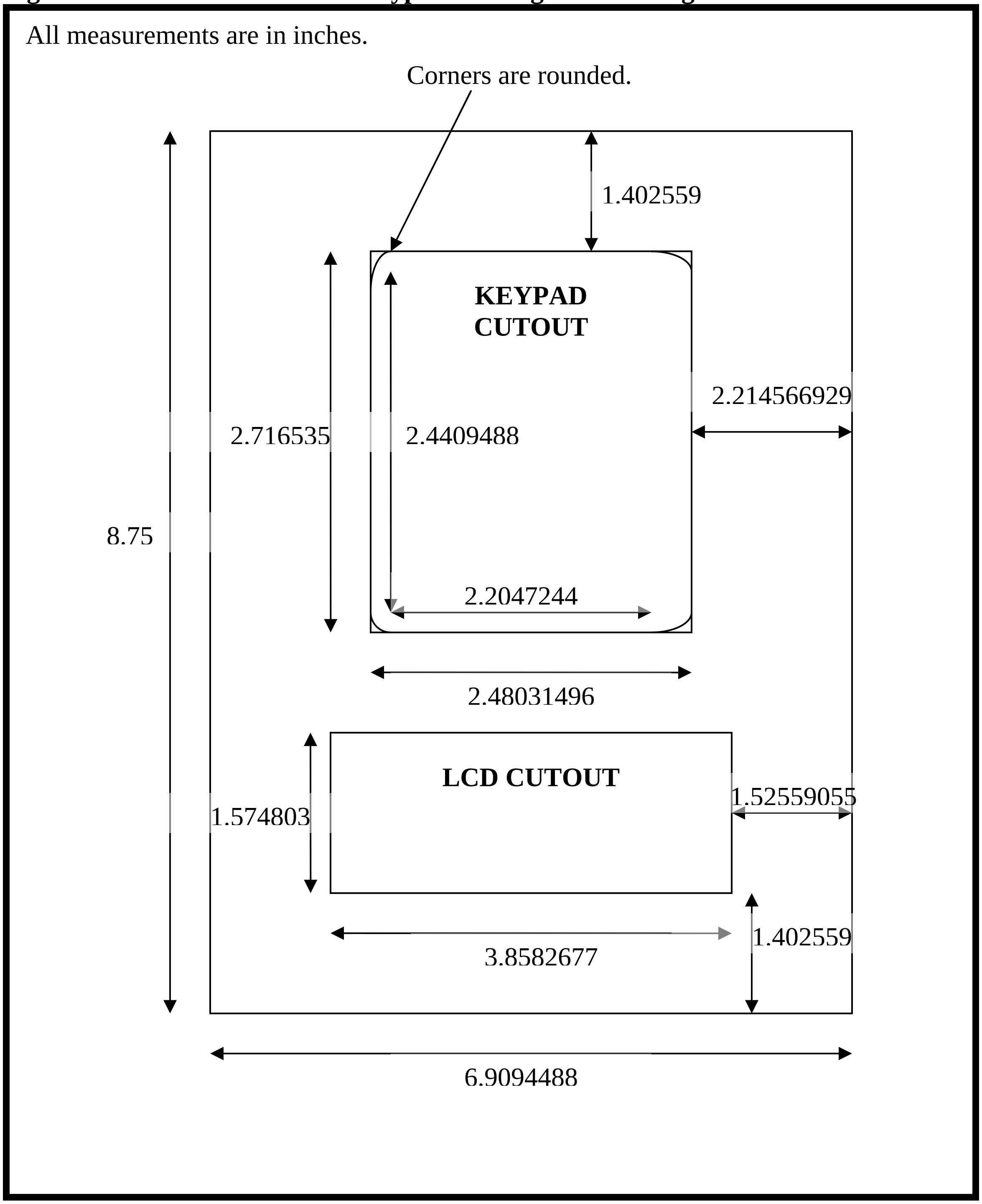


Figure A16: Water Enclosure Mounting Board Dimensions

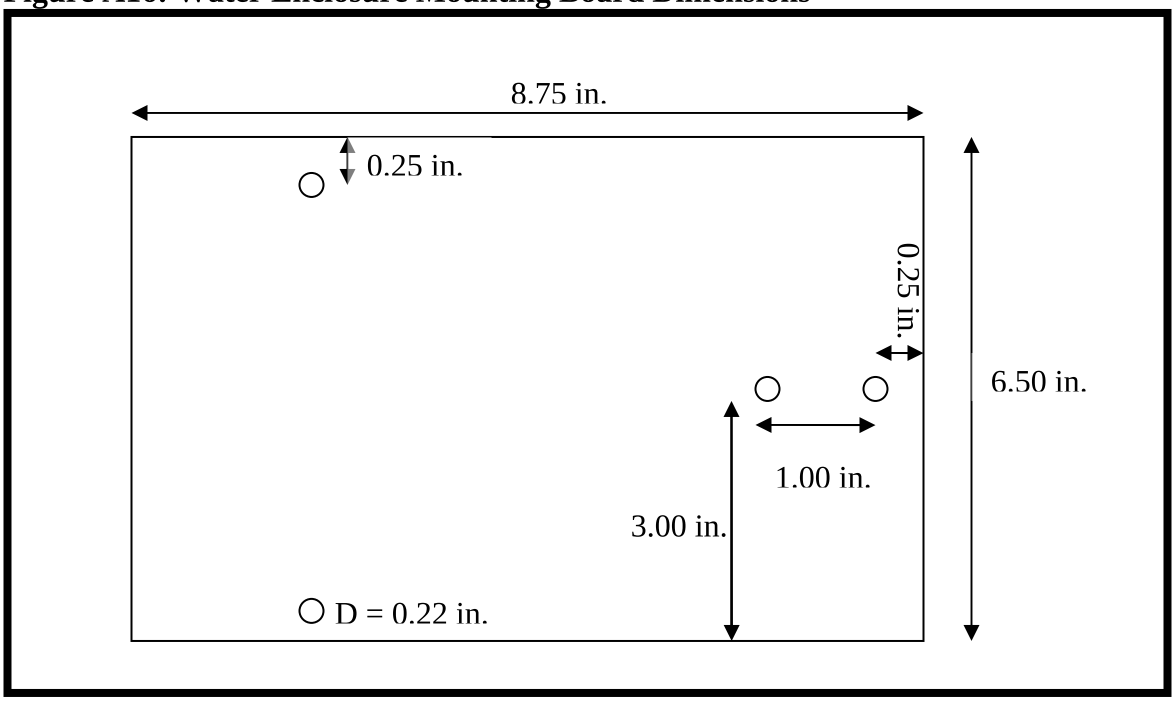


Figure A17: Water LCD/Keypad – Plexiglas Mounting Board Dimensions

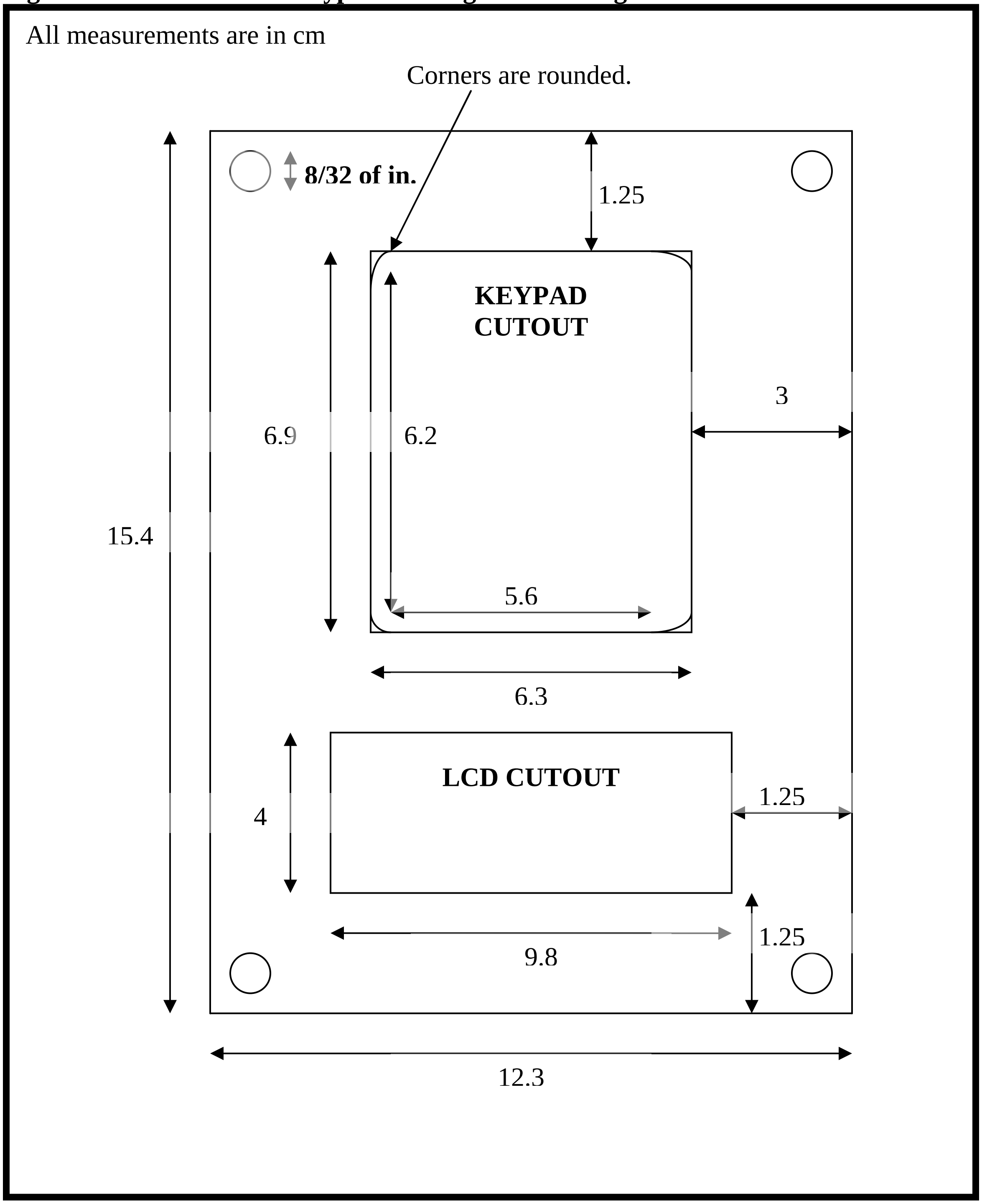
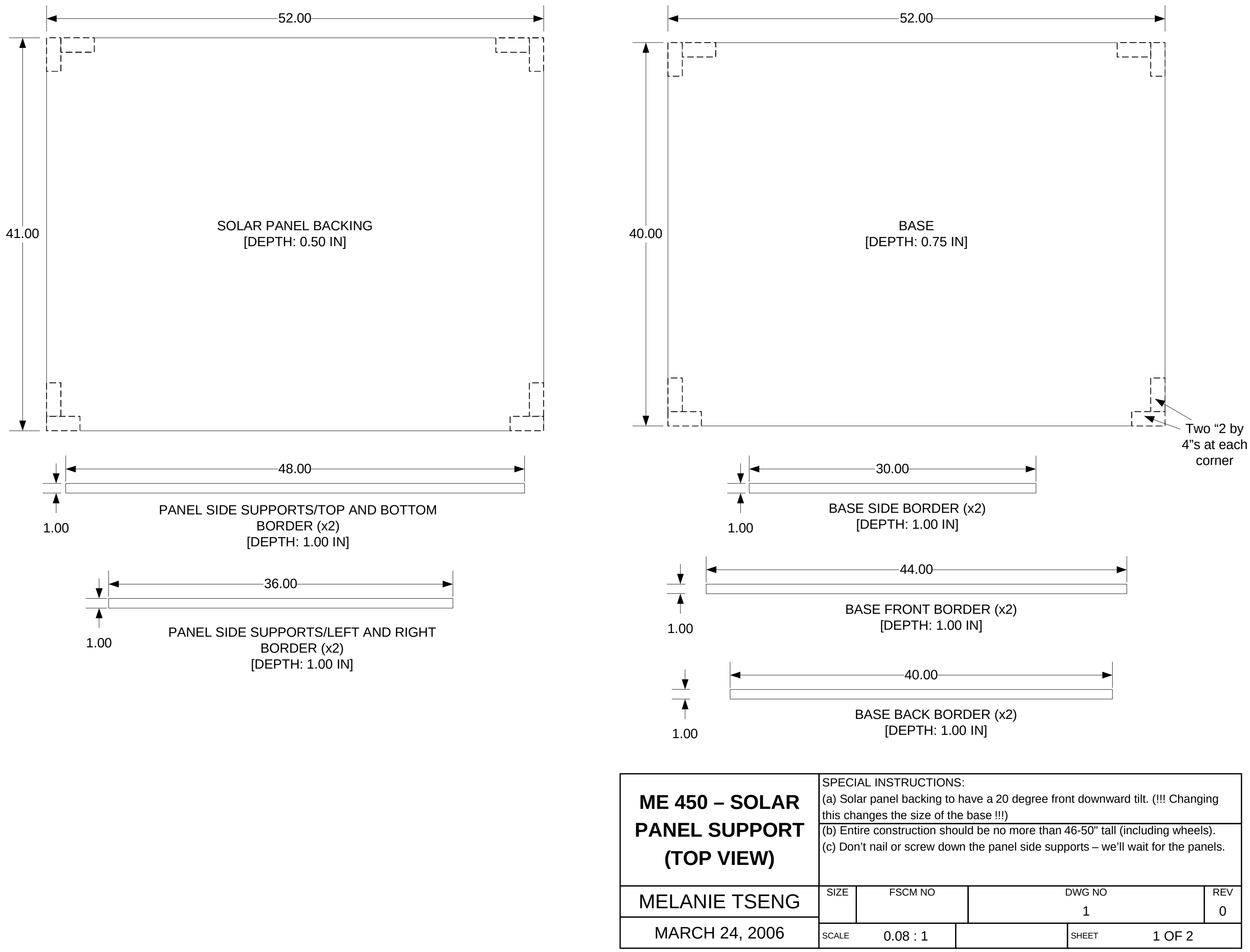
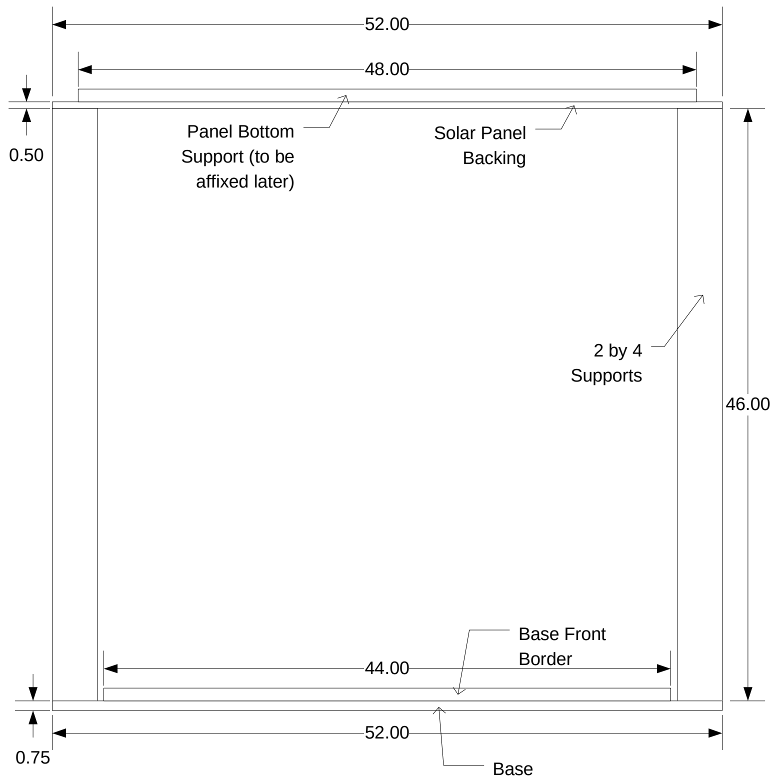


Figure A18: Solar Panel Cart Dimensions





ME 450 – SOLAR PANEL SUPPORT (FRONT VIEW)

SPECIAL INSTRUCTIONS:
(a) Solar panel backing to have a 20 degree front downward tilt. (!!! Changing this changes the size of the base !!!)
(b) Entire construction should be no more than 46-50" tall (including wheels).
(c) Don't nail or screw down the panel side supports – we'll wait for the panels.

MELANIE TSENG

MARCH 24, 2006

SIZE	FSCM NO	DWG NO	REV
		2	0

SCALE	0.08 : 1		SHEET	2 OF 2

Figure A19: Water.csv

Year-month-dayT0hour:00:00	AWcounts	AWtotal
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
2006-4-13T13:00:00	17	9687
2006-4-13T14:00:00	62	9687
2006-4-13T15:00:00	1	9687
2006-4-13T16:00:00	52	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687
0-0-0T00:00:00	0	9687

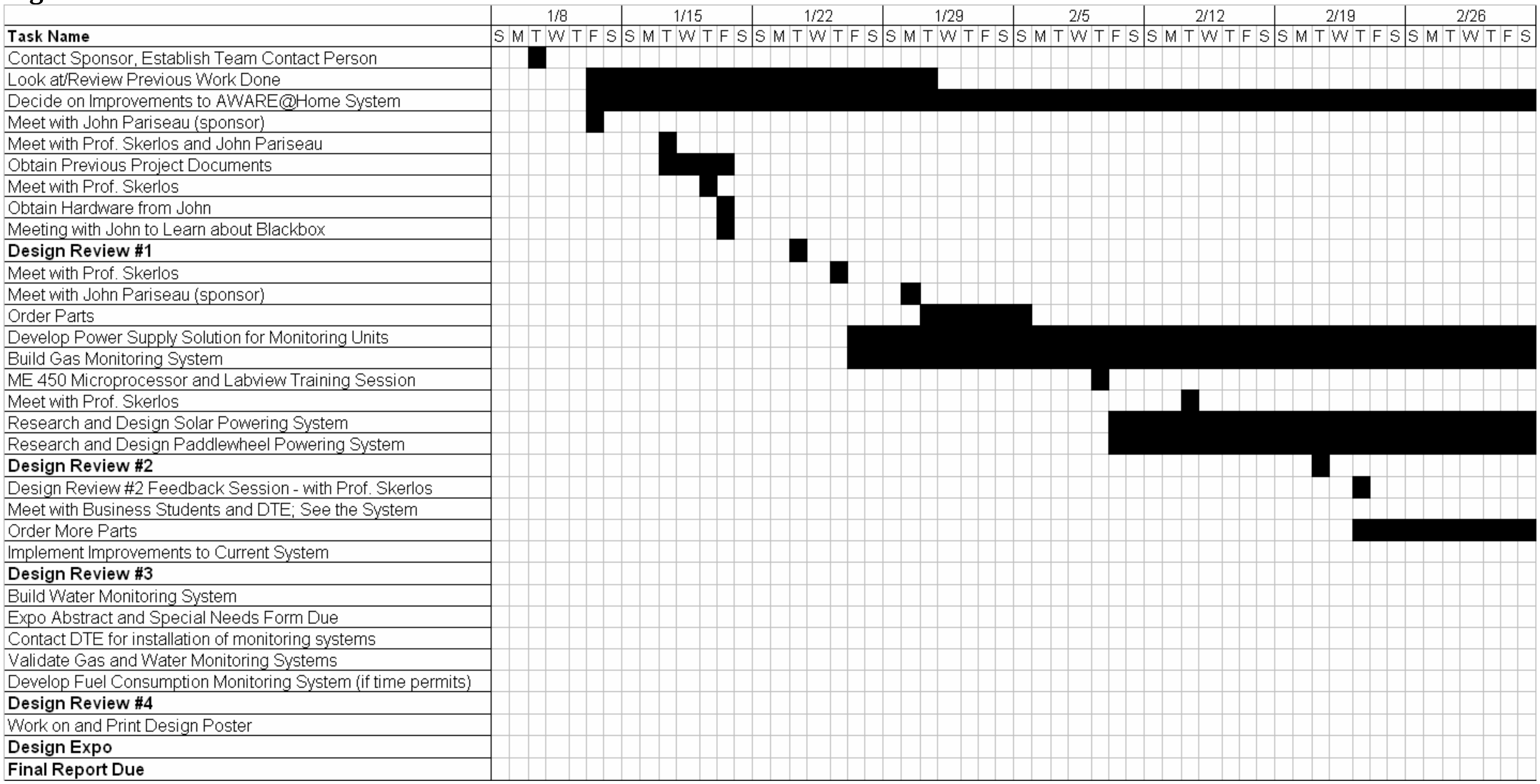
Figure A20: TestWater.xml


```
- <DataRecords>
  - <Record>
      <PointID>UMFieldHouseWater1</PointID>
      <TimeStamp>2006-04-13T10:33:31</TimeStamp>
      <Value>3.78701298701299</Value>
      <Status>0</Status>
    </Record>
  </DataRecords>
```


Figure A21: XMLlogWater.cvs

2006-04-13T10:32:05	2.777142857	<ErrorList><Success>SiEIServer.dll/XMLPost</Success></ErrorList>
2006-04-13T10:32:49	2.777142857	<ErrorList><Success>SiEIServer.dll/XMLPost</Success></ErrorList>
2006-04-13T10:33:33	3.787012987	<ErrorList><Success>SiEIServer.dll/XMLPost</Success></ErrorList>

Figure A22: Gantt Chart



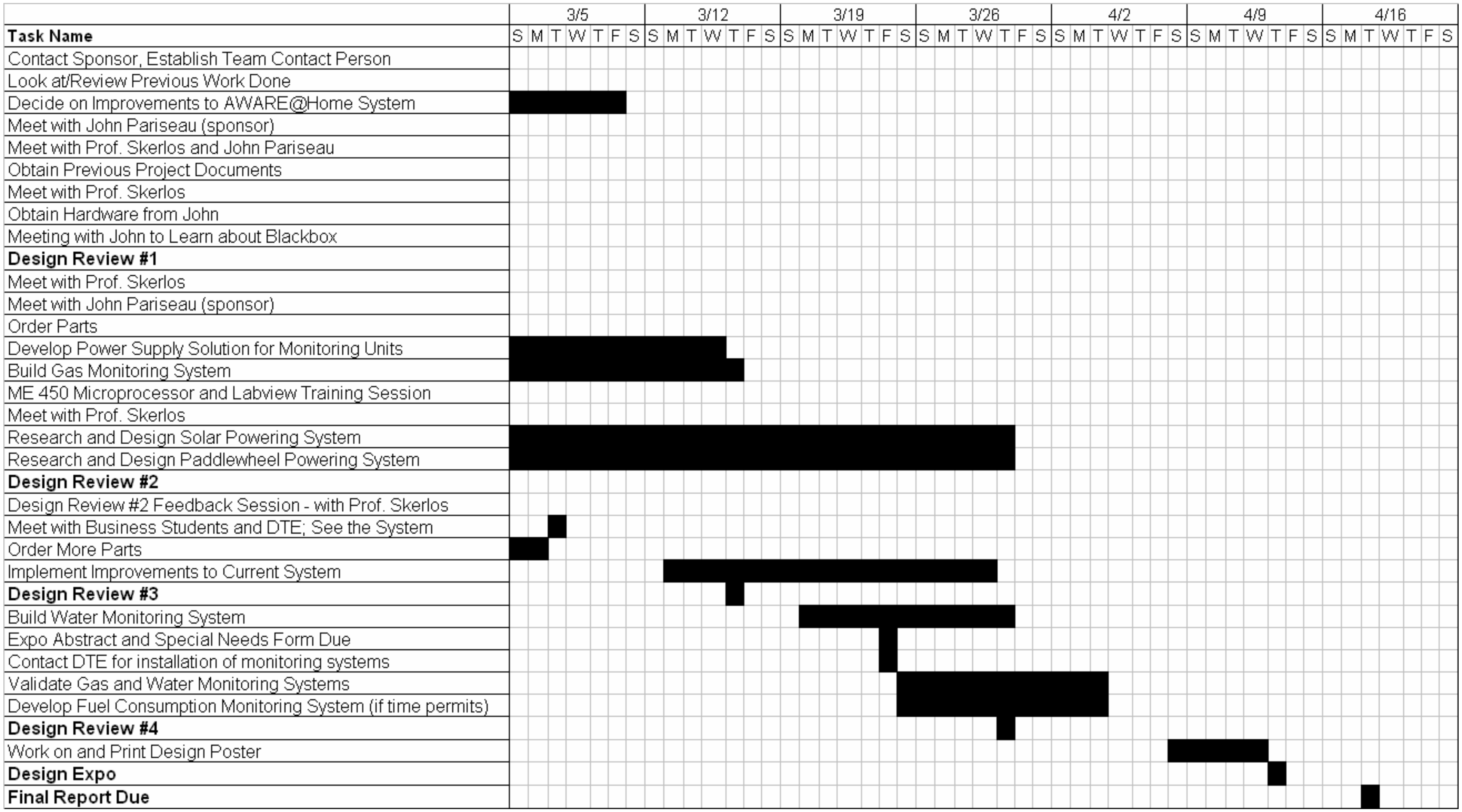
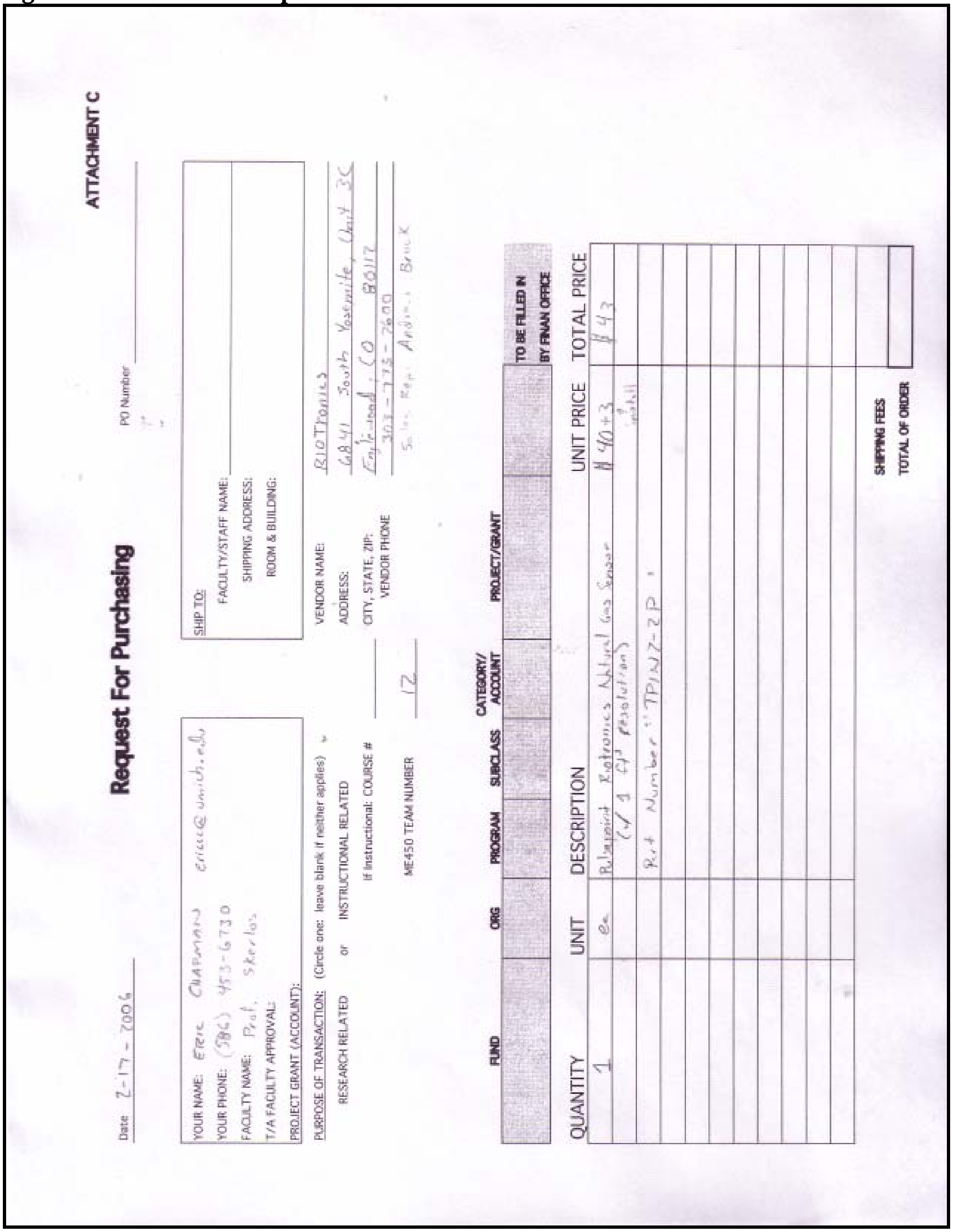

3/5
3/12
3/19
3/26
4/2
4/9
4/16
Task Name
S M T W T F S
Contact Sponsor, Establish Team Contact Person
Look at/Review Previous Work Done
Decide on Improvements to AWARE@Home System
Meet with John Pariseau (sponsor)
Meet with Prof. Skerlos and John Pariseau
Obtain Previous Project Documents
Meet with Prof. Skerlos
Obtain Hardware from John
Meeting with John to Learn about Blackbox
Design Review #1
Meet with Prof. Skerlos
Meet with John Pariseau (sponsor)
Order Parts
Develop Power Supply Solution for Monitoring Units
Build Gas Monitoring System
ME 450 Microprocessor and Labview Training Session
Meet with Prof. Skerlos
Research and Design Solar Powering System
Research and Design Paddlewheel Powering System
Design Review #2
Design Review #2 Feedback Session - with Prof. Skerlos
Meet with Business Students and DTE; See the System
Order More Parts
Implement Improvements to Current System
Design Review #3
Build Water Monitoring System
Expo Abstract and Special Needs Form Due
Contact DTE for installation of monitoring systems
Validate Gas and Water Monitoring Systems
Develop Fuel Consumption Monitoring System (if time permits)
Design Review #4
Work on and Print Design Poster
Design Expo
Final Report Due

Figure A23: RIOTronics purchase order



ATTACHMENT C

Date 2-17-2006

Request For Purchasing

PO Number

YOUR NAME: Eric Chapman ericc@umich.edu
YOUR PHONE: (586) 453-6730
FACULTY NAME: Prof. Skerlos
T/A FACULTY APPROVAL:
PROJECT GRANT (ACCOUNT):

SHIP TO:
FACULTY/STAFF NAME:
SHIPPING ADDRESS:
ROOM & BUILDING:

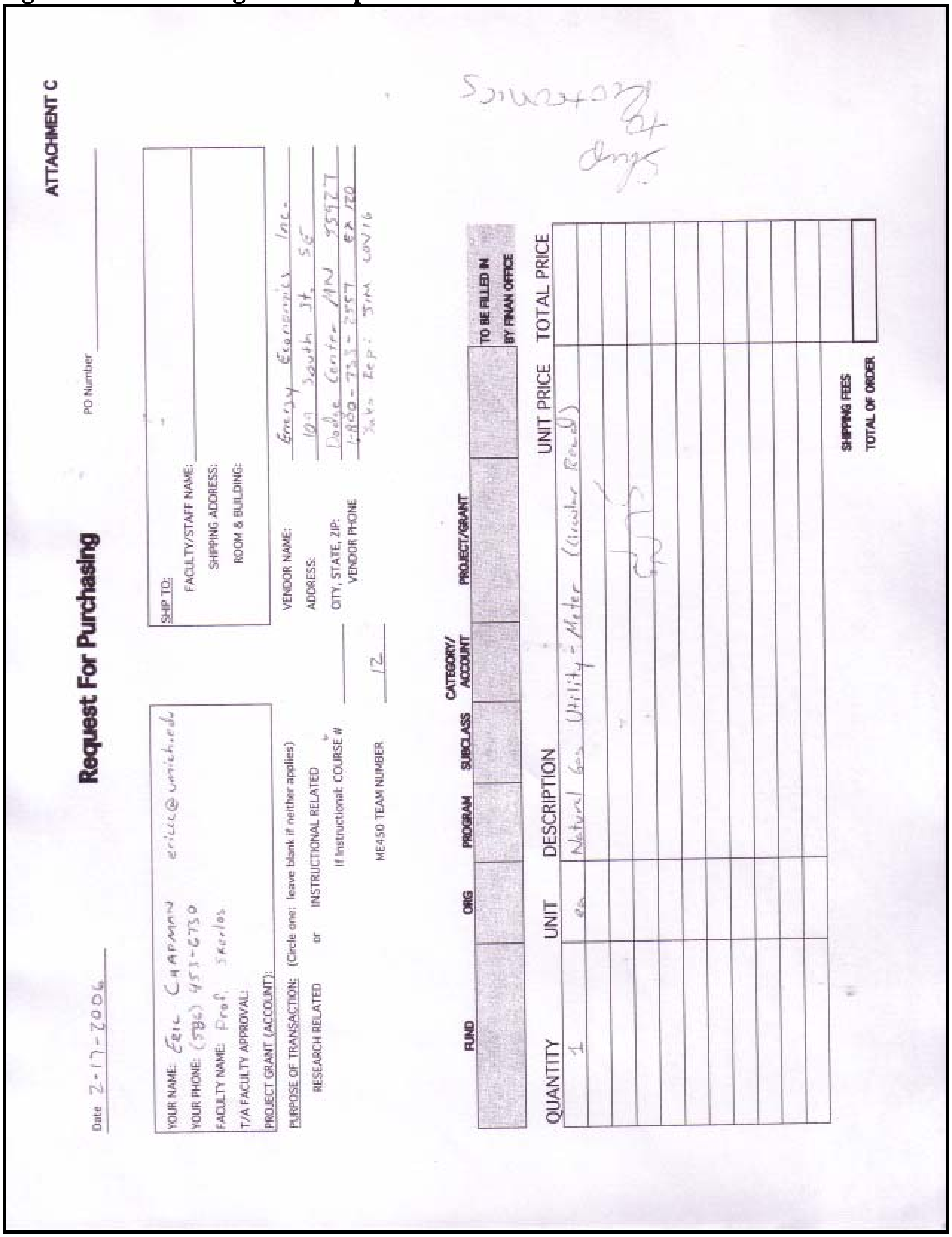
PURPOSE OF TRANSACTION: (Circle one: leave blank if neither applies)
RESEARCH RELATED or INSTRUCTIONAL RELATED
If Instructional: COURSE #
ME450 TEAM NUMBER 12

VENDOR NAME: RIOTronics
ADDRESS: 6841 South Yosemite, Unit 3C
CITY, STATE, ZIP: Englewood, CO 80112
VENDOR PHONE 303-773-2600
Sales Rep: Andrew Brock

FUND	ORG	PROGRAM	SUBCLASS	CATEGORY/ ACCOUNT	PROJECT/GRANT		TO BE FILLED IN BY FINAN OFFICE

QUANTITY	UNIT	DESCRIPTION	UNIT PRICE	TOTAL PRICE
1	ea	Pulsepoint Riotronics Natural Gas Sensor	$40+3	$43
		(w/ 1 ft³ resolution)	install	
		Part Number "TPINZ-2P"		
			SHIPPING FEES	
			TOTAL OF ORDER	

Figure A24: Natural gas meter purchase order



ATTACHMENT C

Request For Purchasing

Date 2-17-2006

PO Number

YOUR NAME: Eric Chapman ericc@umich.edu
YOUR PHONE: (586) 453-6730
FACULTY NAME: Prof. Skerlos
T/A FACULTY APPROVAL:
PROJECT GRANT (ACCOUNT):

SHIP TO:
FACULTY/STAFF NAME:
SHIPPING ADDRESS:
ROOM & BUILDING:

PURPOSE OF TRANSACTION: (Circle one: leave blank if neither applies)
RESEARCH RELATED or INSTRUCTIONAL RELATED
If Instructional: COURSE #
ME450 TEAM NUMBER 12

VENDOR NAME: Energy Economics Inc.
ADDRESS: 101 South St. SE
CITY, STATE, ZIP: Dodge Centre, MN 55927
VENDOR PHONE 1-800-733-2557 Ext 120
Sales Rep: Jim Lovig

FUND	ORG	PROGRAM	SUBCLASS	CATEGORY/ ACCOUNT	PROJECT/GRANT	TO BE FILLED IN BY FINAN OFFICE

QUANTITY	UNIT	DESCRIPTION	UNIT PRICE	TOTAL PRICE
1	ea	Natural Gas Utility Meter (Circular Read)		

SHIPPING FEES
TOTAL OF ORDER

Figure A25: 802.11b purchase order

ATTACHMENT C

Date Feb. 2

Request For Purchasing

PO Number

YOUR NAME: Brad Fetters
YOUR PHONE: (586) 242-2097
FACULTY NAME: Skerlos
T/A FACULTY APPROVAL:
PROJECT GRANT (ACCOUNT): 047912

SHIP TO:
FACULTY/STAFF NAME: Skerlos
SHIPPING ADDRESS:
ROOM & BUILDING:

PURPOSE OF TRANSACTION: (Circle one: leave blank if neither applies)
RESEARCH RELATED or INSTRUCTIONAL RELATED
If Instructional: COURSE #
ME450 TEAM NUMBER 12

VENDOR NAME: DPac Technologies
ADDRESS: 7321 Lincoln Way
CITY, STATE, ZIP: Garden Grove, CA 92841
VENDOR PHONE (800) 642-4477
→ ext: 130 Mo Kanla possible University discount
Michigan Rep: (440)-461-1301 ? Could save $50

FUND	ORG	PROGRAM	SUBCLASS	CATEGORY/ ACCOUNT	PROJECT/GRANT		TO BE FILLED IN BY FINAN OFFICE

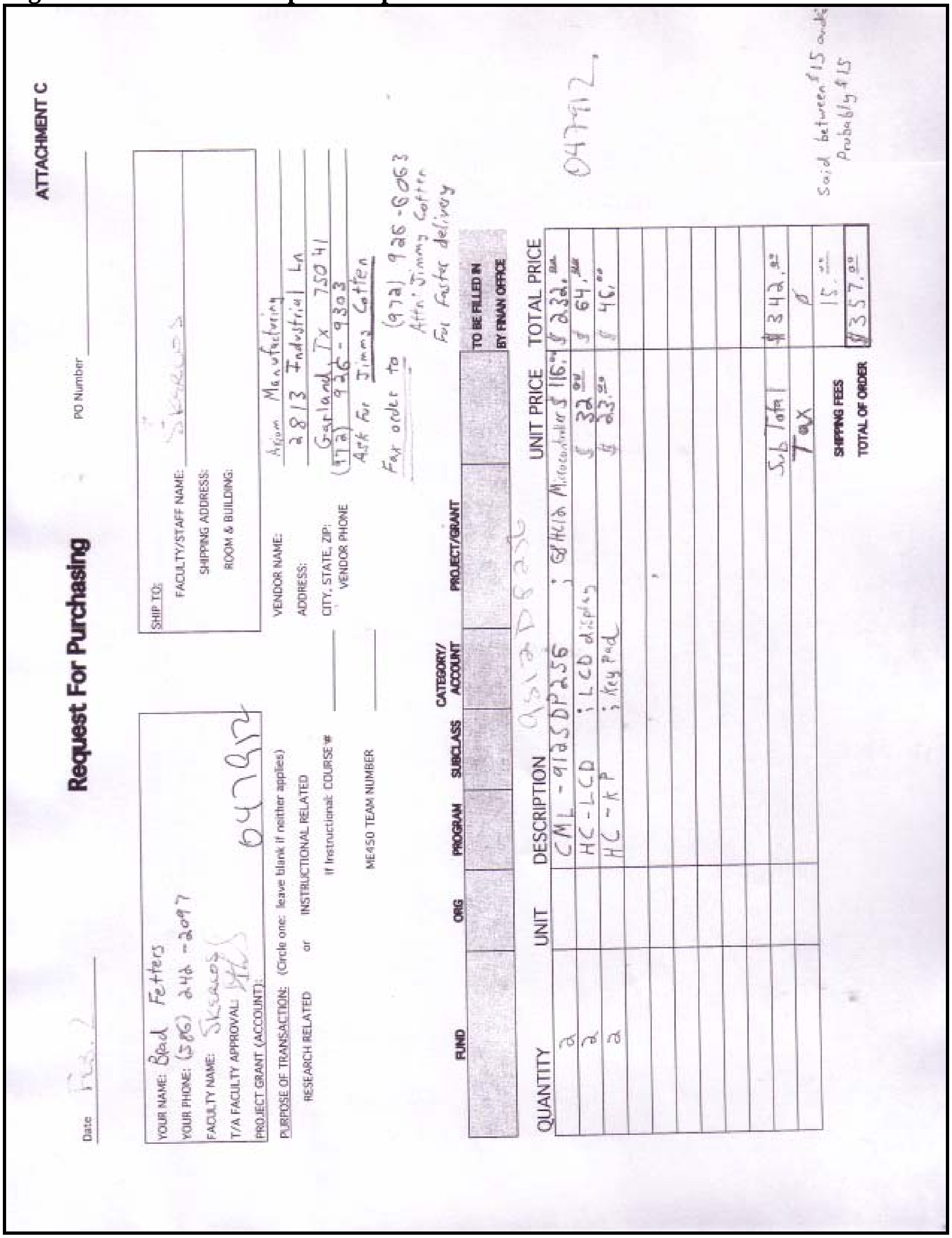
QUANTITY	UNIT	DESCRIPTION	UNIT PRICE	TOTAL PRICE
2		P# ABDB-SE-DP101 ; Wireless Serial Link	230.00	460.00
		Made by Airborne Direct		

SHIPPING FEES ???
TOTAL OF ORDER

$ 199

2/3/06

Figure A26: AH Box components purchase order



ATTACHMENT C

Request For Purchasing

Date: Feb. 2

PO Number: Skaalos

YOUR NAME: Brad Fetters
YOUR PHONE: (386) 248-2097
FACULTY NAME: Skaalos
T/A FACULTY APPROVAL:
PROJECT GRANT (ACCOUNT): 047912

PURPOSE OF TRANSACTION: (Circle one: leave blank if neither applies)
RESEARCH RELATED or INSTRUCTIONAL RELATED
If Instructional: COURSE #
ME450 TEAM NUMBER

SHIP TO:
FACULTY/STAFF NAME:
SHIPPING ADDRESS:
ROOM & BUILDING:

VENDOR NAME: Arjum Manufacturing
ADDRESS: 2813 Industrial Ln
CITY, STATE, ZIP: Garland, Tx 75041
VENDOR PHONE: (972) 926-9303
Ask for Jimmy Cotten
Fax order to (972) 926-6063 Attn: Jimmy Cotten
For faster delivery

FUND	ORG	PROGRAM	SUBCLASS	CATEGORY/ ACCOUNT	PROJECT/GRANT	TO BE FILLED IN BY FINAN OFFICE

QUANTITY	UNIT	DESCRIPTION	UNIT PRICE	TOTAL PRICE
2		CML-9125DP256 ; 68HC12 Microcontroller	$116.00	$232.00
2		HC-LCD ; LCD display	$32.00	$64.00
2		HC-KP ; Key Pad	$23.00	$46.00
			Sub Total	$342.00
			Tax	∅
			SHIPPING FEES	15.00
			TOTAL OF ORDER	$357.00

Said between $15 and ... Probably $15

047912

Figure A27: Bill of Materials

Part Number	Part Name	Distributor	Quantity	Total Cost
ABDB-SE-DP101	Wireless Serial Link	DPAC	2 (1)	$ 460.00
CML-912SDP256	Microcontroller	AXIOM	2 (1)	$ 232.00
HC-LCD	LCD Display	AXIOM	2 (1)	$ 64.00
HC-KP	Keypad	AXIOM	2 (1)	$ 46.00
NB141207-100	NEMA Enclosure (Gas Only)	Hyperlink	1 (1)	$ 179.00
ASR-PG13	G-13.5 Conduit Connector (used in NEMA Enclosure)	Hyperlink	1 (1)	$ 3.95
ASR-PG16	PG-16 Conduit Connector (used in NEMA Enclosure)	Hyperlink	1 (1)	$ 3.95
69945 K999	Weatherproof Enclosure (Water Only)	Mcmaster-Carr	1(1)	$ 77.90
N/A	Circular Read Nat. Gas Meter	EEI	1	$ 75.00
TPIN2-2P	RIOTronics PulsePoint (1 ft^3)	RIOTronics	1 (1)	$ 43.00
DS1305	Maxim Time Chip	Digikey	4 (1)	$ 20.24
SS441A	Honeywell Hall Sensor (Water Only)	Digikey	4 (1)	$ 8.60
CFS-32.768KDZB-UB	Time Chip Crystal	Digikey	4 (1)	$ 1.12
N/A	100 Ohm Resistor	N/A	2 (1)	$ 0.00
N/A	1000 Ohm Resistor	N/A	2 (1)	$ 0.00
N/A	47,000 Ohm Resistor	N/A	2 (1)	$ 0.00
N/A	PNP Transistor	N/A	2 (1)	$ 0.00
EEC – S0HD104V	0.1F 5.5V Capacitor	Digikey	4 (1)	$ 7.92
FCXX10M2	Paddle Wheel Flowmeter Coil Sensor, 1" pipe	Blue-White Industries	1 (1)	$ 290.30
04-1086	ThinFilm Series Solar Panel (Gas Only)	Silicon Solar	2 (2)	$ 359.90
ETX12	12 V AGM Battery (Water Only)	Extreme Magna Power	1(1)	$ 52.99
UB121100	Universal Battery (Gas Only)	Creative Energy Technologies	2 (2)	$ 308.48
Xantrex	PROwatt 150 Modified Sine Wave Inverter	Infinigi	2 (1)	$ 66.56
DX-UBDB9	USB to serial adapter	Dynex	1	$ 35.99
TOTAL				$ 2336.90

This table provides a list of parts that we have ordered for our project. This list includes the part number, part name, distributor, and cost. Funds for the parts purchased have come from grant money given to Professor Skerlos that he has provided us for this project. Sample copies of completed purchase orders are provided in Figures 10A-13A.

APPENDIX B: Solar Panel Calculations and Corresponding Specifications

Amp Hours Consumed Per Day

AC Loads	Watts	(x) Hrs/wk	(=) WH/wk	
Wireless DPAC	2	168	336	INPUT
Microcontroller (60 mA @ 5V)	0.3	168	50.4	INPUT
Other components (estimate)	0.7	168	117.6	INPUT
-				INPUT
-				INPUT
-				INPUT
		Total WH/wk	504	
(x 1.25) Inverter loss and battery efficiency			630	
(12, 24, or 48 volts) Inverter DC input voltage/DC system voltage			12	INPUT
Total amp hours used per week by AC loads			52.5	

DC Loads	Watts	(x) Hrs/wk	(=) WH/wk
-			
-			
		Total WH/wk	0
(12, 24, or 48 volts) DC system voltage			12
Total amp hours used per week by DC loads			0
Total amp hours used per week by AC loads			52.5
Total amp hours used per week by all loads			52.5
Total average amp hours per day			**7.5**

Total Required Solar Array Amps

Total amp hours used per day	7.5	
(x 1.2) Loss from battery charge/discharge	9	
Average sun hours per day in the area	2.7	INPUT
Total solar array amps required	**3.3333**	

Optimum Battery Size

Total amp hours used per day		7.5	7.5	
Maximum number of continuous cloudy days in the area		30	10	INPUT
		225	75	
(/ 0.8) Maintain a 20% reserve after the deep discharge period		281.25	93.75	
If using a lead-acid battery, choose multiplier which corresponds to the battery's winter time average ambient temperature		1.59	1.59	INPUT
Temperature	Multiplier			
80 F/26.7 C	1			
70 F/21.2 C	1.04			
60 F/15.6 C	1.11			
50 F/10.0 C	1.19			
40 F/4.4 C	1.3			
30 F/-1.1 C	1.4			
20 F/-6.7 C	1.59			
Optimum battery size (in amp-hours)		**447.19**	**149.0625**	

<u>Prototype: Solar Panel Specifications</u>

Silicon Solar ThinFilm Series (Item number: 04-1086) [16]

- Manufacturer/Supplier: Silicon Solar
- Open circuit voltage: 16-18 volts (12 volt configuration)
- Short circuit current: 1800-2000 mA
- Watts: 28
- Dimensions: 24”x 37” x 0.5”
- Cost: $179.95 (not including shipping, handling, etc.)

<u>Prototype: Charge Controller Specifications</u>

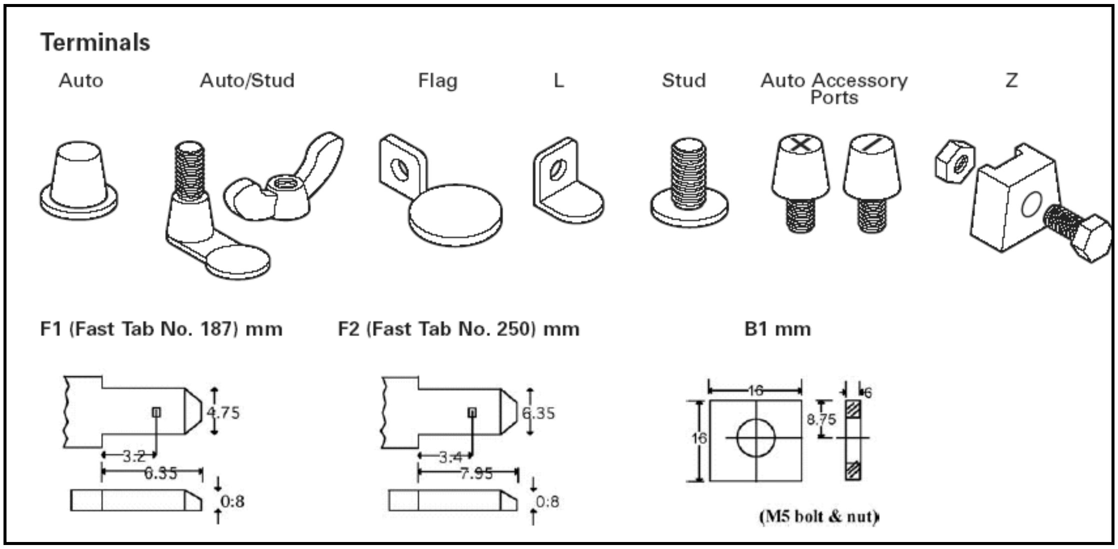
SolarController (Item number: 12-FSOLARCON) [17]

- Manufacturer/Supplier: Brunton
- Dimensions: 3.8” x 2.7” x 1”
- Weight: 4.2 ounces
- Handles up to 7 amps of array input, 100 watts of solar power
- Maintains battery in fully charged state
- Charge light indicates charging
- Leave battery connected for constant charge monitoring
- Designed for continuous charging with 10 watt and larger solar panels
- Cost: $30.00 (not including shipping, handling, etc.)

<u>Prototype: Battery Specifications</u>

Universal Battery UB121100 [18,19]

- Manufacturer: Universal Battery
- Supplier: Creative Energy Technologies
- 12 volt
- Amp hour capacity (20 hour rate): 110
- Terminals: Flag/L-Blade/B2 (see Figure X below)
- Dimensions: 13” x 6.75” x 10.50”
- Weight: 71.10 (lbs?)
- Cost: $154.25 (not including shipping, handling, etc.)



Prototype: DC/AC Power Inverter Specifications

Xantrex PROwatt 150 Modified Sine Wave Inverter [21]

- Manufacturer: Xantrex
- Supplier: Infinigi
- Voltage: 12 V
- Maximum AC power: 150 W
- Surge capacity (peak): 400 W
- Peak efficiency: 90%
- No load current draw: 0.15 A
- Input voltage range: 10-15 VDC
- Dimensions (H x W x L): 1.9” x 4.7” x 4.7”
- Weight: 1.3 pounds
- Regulated output protects sensitive equipment
- Auto shutdown
- Silent operation
- Cost: $33.28 (not including shipping, handling, etc.)

APPENDIX C: Engineering Changes since Design Review #3

Due to the structure of our project and project goals, we had very few engineering changes since Design Review 3. Most of the work that has been completed since Design Review 3 has been simple implementation of the ideas and concepts previously generated. However, there were a couple of changes that needed to be accounted for.

Paddle Wheel

One such change is the need for a different sized paddle wheel. We have recommended in our report that the future of this project further investigate the paddle wheel and the power it outputs. Unfortunately, we did not receive the paddle wheel in enough time to analyze the system and make alterations accordingly. After ordering the paddle wheel component and doing some further analysis, we found that the paddle wheel will not provide enough current and voltage to charge the battery that powers the water AWARE@Home box. Therefore, this issue and needs to be addressed as defined in our report.

Validation Approaches

Before we began implementing our validation approaches, we were unsure of the exact methods and tests that would be used. We planned a general validation approach to different parts of our system but some additions to this approach were made as we carried out the project. This required numerous trips to the hardware store to buy correctly fitted pipes and attachments for the water and gas meters but in the end we were satisfied with our result.

Natural Gas Monitoring

In terms of the natural gas validation approach, we knew that we had to connect piping and the air compressor together. This was a fairly easy task. However, the most serious engineering change that needed to be addressed was to connect a valve on the outlet portion of the gas meter to create a back pressure. Without this valve, our validation approaches would not have been successful.

Additionally, validation of the natural gas AWARE@Home box and the connection of RIOTronics to the box did not occur as originally planned.

Water Monitoring

In the water monitoring unit, the only engineering change that arose was verifying the accuracy of the dial read outs. We initially only wanted to test whether or not they functioned when water was flowing through, but later decided that we needed to quantify the amount of water flowing through the meter and compare it to what the dials read.