Validation Document for Dynamic Parking Signage Project

ELEC 491 Capstone Design Project

Team PL-89

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1. Summary

This document presents our validation strategy for the design decisions throughout the project. It aims to verify the decisions listed in **Key Document 2 - Design Document**. Emphasis is put on the client's requirements and constraints presented during client meetings. The tests can be separated into two categories - the management system and the device. Below lists the tests conducted and the final results.

Management System Tests			
Requirements tested	**Section**	**Results**	**Pass/Fail/ NA**
Cellular communication between device and management system	**2.1.1**	LED can be turned on/off using web app through cellular communication	✔
Time the sign takes to update an image	**2.1.2**	Display updated within 30 seconds	✔
Communication between the management system and Eleven-X server	**2.1.3**	Unable to test; we were unable to reach Eleven-X contact to help establish a connection between gateway and PlacePod server.	N/A
Device Tests			
Requirements tested	**Section**	**Results**	**Pass/Fail/ NA**
Power system sleep mode	**2.2.1**	Validation could not be completed due to the COVID-19 outbreak	N/A
Power management testing		Validation could not be completed due to the COVID-19 outbreak	N/A
E-paper quality in low temperatures	**3.1.1**	Validation could not be completed due to the COVID-19 outbreak	N/A
Motion sensor and integration	**3.1.2**	Validation could not be completed due to the COVID-19 outbreak	N/A
Power consumption test	**3.2.1**	Validation could not be completed due to the COVID-19 outbreak	N/A

Battery life test	**3.2.2**	Validation could not be completed due to the COVID-19 outbreak	N/A
LED power test	**3.2.3**	Validation could not be completed due to the COVID-19 outbreak	N/A
PCB tests	**3.3**	Unable to complete most tests due to the COVID-19 outbreak. See section 3.3 for full results	✘
Enclosure testing (Durability & IP)	**3.4**	Validation could not be completed due to cancellation of waterjet cutting service during	N/A
Integrated testing	**3.5**	Failed. Some of the previous tests failed.	✘
Data Plan is Active	**4.1**	Passed.	✔
Cellular Development Board Can Access Internet	**4.2**	Passed.	✔
E-ink Goodisplay Hardware	**4.3**	Passed.	✔
Test Display Code Migration to Prototype Hardware	**4.4**	Failed.	✘

Table 1. Summary of Tests Results

2. System Validation

This section defines the validation methods to be used to verify proper sign operation with an emphasis on subsystems behaving as defined. Figure 1 gives an overview of the system of interest.

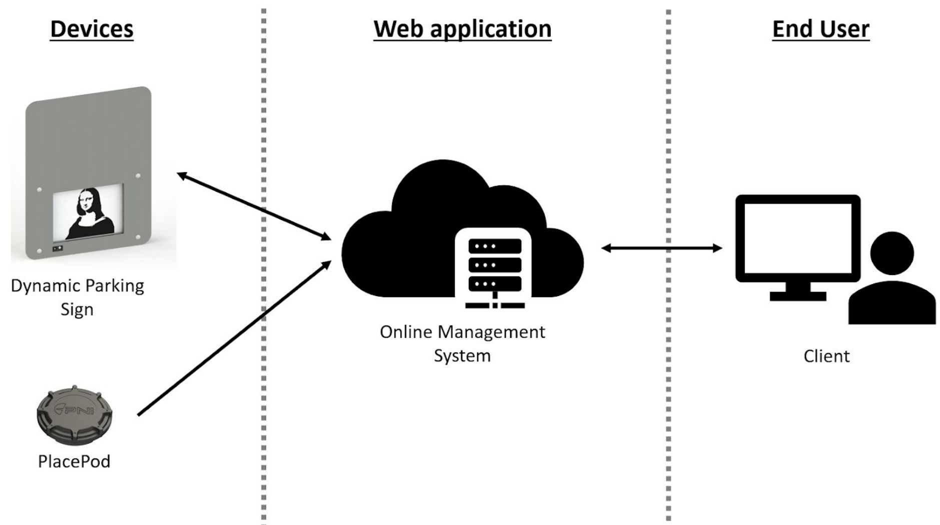

Figure 1. A High-Level Overview of the Complete System

2.1 Communication Systems Validation

This section focuses on the communication between various subsystems for proper sign operation. The systems include the dynamic signage device, management system, and the UBC Parking LoRa server.

2.1.1 Cellular Communication with Management System

Objective: Validate communication between the sign and the management system through cellular communication - **FR2**.

Procedure:

1. Power on the dynamic signage device.
2. Open management system (web app) and log in with appropriate credentials using a laptop computer connected to the internet.
3. Upload a new stall restriction in the form of an image to the sign.
4. Instruct sign to change current parking restriction to the newly uploaded restriction.
5. Allow for adequate time for the sign to change.

Pass Condition: Cellular communication established; control of sign can be completed through the server.
Fail Condition: Cellular communication not established; no communication between the sign and server.
Results: Pass, LED can be turned on/off using web app through cellular communication

2.1.2 Sign Update Time

Objective: Validate 4G/LTE communication between the server and the dynamic signage device completed within 2 minutes - based on **NFR2**.

Server to sign
Procedure:

1. Repeat steps 1 through 4 in section 2.1.1.
2. Record the time required for an image update to the newly uploaded restriction.

Pass Condition: The sign update is within 2 minutes.
Fail Condition: The sign update is beyond 2 minutes.
Results: Pass, sign updated within 30 seconds of sending a signal from server

2.1.3 Management System Communication with PlacePod Gateway

Objective: Validate communication between the management system with the PlacePod gateway to update the stall occupancy - **FR1**.

Procedure:

1. Open our management application on a computer.
2. Verify vacant stalls from the PlacePod server.
3. Have a vehicle park above a PlacePod.
4. Observe the management system to check if the stall changes to occupied.

Pass Condition: The management system shows a vacant stall when no vehicle is present and an occupied stall when a vehicle is present.
Fail Condition: No communication from the management server to the PlacePod server.
Results: Unable to test; Our team was unable to reach Eleven-X contact to help establish connection between the gateway and the PlacePod server.

2.2 Power System Validation

2.2.1 Sleep Mode

Objective: Validate the processor will remain in a sleep mode until the wake-up signal is sent via cellular.

Procedure:

1. Power on dynamic signage device.
2. Verify the board state.
3. Set the processor to sleep mode.

Pass Condition: The processor remains in sleep mode until a wake-up signal is received
Fail Condition: The processor does not wake up after the signal is received or the processor wakes up without receiving a wake-up signal.
Results: Validation could not be completed due to COVID-19 outbreak

3. Firmware and Hardware Validation

This section will record all analysis and testing of firmware and hardware of this project.

3.1 Display Testing

Display validation will be used to validate if the firmware for the display is behaving as defined in requirements.

3.1.1 Display firmware in Low Temperatures Test

Objective:
This test will validate if our firmware that controls the display behaves as specified i.e. keep the display readable by flashing extra times when the temperature is near 0 degrees, the coldest temperature (the assumption that device is only used in Vancouver) we foresee our device to operate in - with respect to **NFR3** (readable from 3 meters). Readable is defined as the image is not faded.

Procedures:

1. Flash an image on 2 e-ink display screens.
2. Put one display in a refrigerator of 0±2℃ and leave the other at room temperature for 10 minutes.

3. Afterward, take the display out. Compare the image shown on the E-ink screen to the one left at room temperature.
4. Repeat for 4 different images, comparing the images after each time.

Pass Condition: All 5 images are not faded.
Fail Condition: Any one of the 5 images are faded.
Results: Validation could not be completed due to COVID-19 outbreak

3.1.2 Motion Sensor and Integration Test

Objective:
To certify the LED turns on under desired conditions, and the field of view for the motion sensor, seen in Figure 2, has >30° angle - **FR4**.

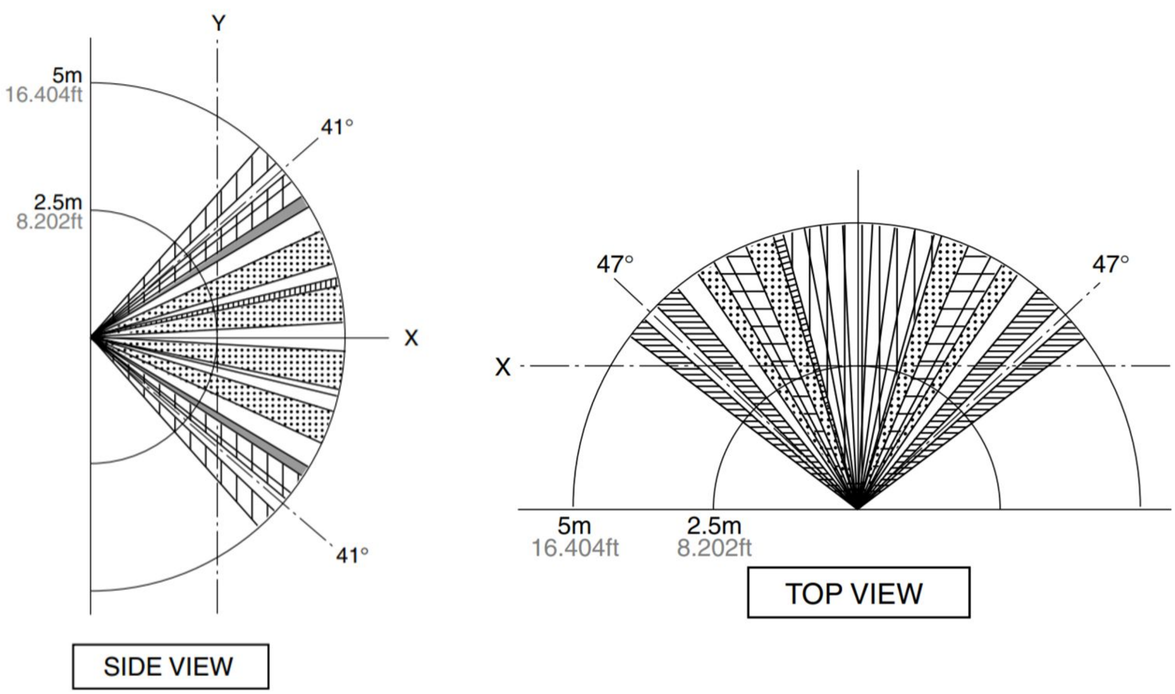

Figure 2. Motion Sensor Visual Field of View

Procedure:

1. Place sensor module at an outdoor parking stall with a motion sensor facing the end of the stall.
2. have a car or person pass the sign.
3. Record when the LED strip turns on and the position of the person or car. Test with the following conditions:
    - Cover light sensor (simulate poor lighting) and completely drive past the sign
    - Cover light sensor (simulate poor lighting) and completely walk past the sign

- Uncover light sensor (simulate good lighting) and completely drive past the sign
- Uncover light sensor (simulate good lighting) and completely walk past the sign

4. Repeat the above conditions again with the proceeding person or car moving slower.

Determine where the resulting positions are when the light first turns on, and if they reside at > 30 degrees angle.

Pass Condition: LEDs light up during low light conditions and motion is detected.
Fail Condition: LEDs do not light up.
Results: Validation could not be completed due to COVID-19 outbreak

3.2 Power Management Testing

With a design focus of 'low power', having good validation for the system is important for the success of our self-sufficient product.

3.2.1 Total Power Consumption Test

Objective:
to determine if the power consumed by the product is below the power budget (included in Appendix B). The test includes the power consumption of all components including the MCU, LEDs, and cellular modem.

Procedure:

1. Connect parking sign up to a power source where accurate power consumption readings are taken.
2. Run through the sign use cases over a period of time.
3. Record the amount of power consumed.

Each of the signs' use-cases will be tested to determine the power consumed with the data recorded in a spreadsheet for documentation and analysis.

Pass Condition: Power consumption allows for the system to last 2 weeks.
Fail Condition: Power consumption too high for the system to last 2 weeks.
Results: Validation could not be completed due to COVID-19 outbreak

3.2.2 Battery Life Test

Objective:
To determine whether the batteries can sustain for two weeks without requiring charging.
Procedure:

1. Connecting all components to the system and removing all sources of power - besides the batteries.
2. In a controlled environment, observe the sign to verify operation.
3. Record the amount of time until the sign powers down.

Each of the signs use-cases will be tested to determine whether the sign will be operational in all applications for the use of the client during low/no light conditions.

Pass Condition: The sign batteries survive for 2 weeks.
Fail Condition: The sign batteries do not survive for 2 weeks.
Results: Validation could not be completed due to COVID-19 outbreak

3.2.3 LED Power Test

Objective:
To estimate how much power the LED strip would use in a night and assess whether it should be included in the prototype. The validation is to check whether the expected power usage from the LEDs is obtained through expected traffic.

Procedure:

1. Contact UBC PAS for the location they plan on setting the sign.
2. Implement system: Arduino board with motion sensor.
3. Develop firmware to store information.
4. Put in a durable (water-sealed) container and tie it to one of the parking sign poles.
5. Collect data for a week.

Pass Condition: The power consumption is below the budgeted value.
Fail Condition: The power consumption is higher than the budgeted value.
Results: Validation could not be completed due to COVID-19 outbreak

3.3 PCB Circuit Behavior Testing

Take each circuit “block” to see if it performs as intended. Each system has a different test procedure and expected outcome. Validation results are found at the end of the section.

Objective: Validate all the systems are operating as intended on the PCB

3.3.1 Reverse Polarity Protection Circuit

1. Isolate the system past the reverse polarity circuit

2. Connect a resistive load to the battery output after the reverse polarity protection circuitry
3. Connect a power supply with + to -, - to + at 8.4V
4. Measure the current drawn
5. Reverse the supply connection (+ to +, - to -)

Pass condition: No current is drawn during reverse connection, the nominal current is drawn during correct polarity connection
Fail condition: Current is drawn during reverse polarity connection

3.3.2 Cell Balancing IC

1. Connect two cells with 500mV difference between them is the nominal voltage range (2.5V to 4.2V)
2. De-populate LEDs, wait one day
3. Check the voltage of each cell

Pass condition: The higher cell voltage is approaching the lower cell voltage significantly
Fail condition: There is no change in the higher cell voltage

3.3.3 Under-voltage Comparator

1. Connect a power supply to the battery + and - terminals
2. Apply 6V, and slowly lower the power supply voltage down to 5V
3. Record the voltage at which the main DC/DC converter turns OFF
4. Gradually raise the supply voltage until the main DC/DC converter turns ON

Pass Condition: The DC/DC converter turns off at 5.2V and turns back on at 5.4V (200mV hysteresis)
Fail Condition: The DC/DC converter does not shut down at the correct voltage, or fault hysteresis is not present upon subsequent supply voltage rise

3.3.4 Over-Temperature Comparator

1. Simulate over temperature on thermistor with a heat gun while the board is powered on

Pass Condition: Main DC/DC converter is shut down
Fail Condition: Main DC/DC converter continues to run

3.3.5 Overcharge

1. Connect 24V, >2A supply to 5.5mm barrel jack power input
2. Connect electronic DC load to battery + and - terminals
3. Set DC load to constant voltage mode
4. Gradually raise the voltage from 7V to 8.6V (overcharge condition)

5. Monitor the current going into the DC load, and note whether the current abruptly stops (MPPT shutdown) when the voltage is raised above 8.4V

Pass Condition: Current stops flowing through the DC load at 8.4V
Fail condition: MPPT continues to deliver current through the DC load past 8.4V

3.3.6 Max Power Point Tracking IC

1. Shine floodlight at the solar panel (max wattage)
2. Connect the solar panel to PCB and monitor its output voltage
3. Connect DC load to battery terminals (without the battery) in constant voltage mode. Set to 7.4V (nominal battery voltage)
4. Measure current going into DC load

Pass Condition: Solar panel voltage is regulated to 17.6V (solar panel max power voltage setpoint)
Fail Condition: Solar panel voltage drops below or stays above 17.6V

3.3.7 5V DC/DC converter & 3.3V linear regulator

1. Power device
2. Measure DC/DC converter output voltage
3. Measure the linear regulator output voltage

Pass Condition: DC/DC converter outputs 5V, and linear regulator outputs 3.3V
Fail Condition: One of the above is not true

3.3.8 SWD Programming Interface

1. Attempt to program the microcontroller using SWD interface with ST-Link debugger

Pass Condition: The microcontroller is programmed successfully
Fail Condition: The microcontroller cannot be programmed

3.3.9 Microcontroller

1. Program microcontroller with test code to flash RGB LED in a specific sequence

Pass Condition: RGB LED flashes with the intended sequence
Fail Condition: The microcontroller cannot execute code, and thus the LED will not flash

3.3.10 Cellular Modem (Pin Connections)

1. Program microcontroller with firmware specifically intended to test cellular module
2. Observe firmware behavior

Pass Condition: The cellular modem operates nominally
Fail Condition: The cellular modem will not operate

3.3.11 Flash Memory

1. Program microcontroller with firmware written to write image array to flash memory chip over SPI
2. Power down device
3. Program microcontroller with firmware to read back image array from flash memory

Pass Condition: A picture is successfully stored in flash memory, and read from flash memory
Fail Condition: A picture cannot be either written, read or both from flash memory

3.3.12 USB to UART IC

1. Flash firmware onto microcontroller to recognize certain characters from UART interface
2. Flash RGB LED in acknowledge sequence for different characters
3. Connect USB between computer and device
4. Check to make sure device drivers for UART chip are installed automatically
5. Install the driver manually if necessary
6. Open a putty connection on 115200 baud rate with the correct COM port
7. Type-specific characters into the terminal and observe RGB LED behavior

Pass Condition: Data can be successfully received by the microcontroller using a USB connection
Fail Condition: Transfer of data fails from USB to the microcontroller

3.3.13 Motion Sensor (passive infrared)

1. Set up the system with enclosure and acrylic glass cover
2. Power system on
3. Flash firmware to recognize digital input from motion sensor input and toggle RGB LED upon the high digital value from motion sensor
4. Create motion in front of the motion sensor at different intervals and distances
5. Observe RGB LED

Pass Condition: The motion sensor outputs a logic one when movement is imposed
Fail Condition: The motion sensor fails to function correctly

3.3.14 Photoresistor

1. Measure photoresistor output voltage under different light exposure conditions

Pass Condition: Voltage reading matches the graph on photoresistor datasheet
Fail Condition: Voltage reading does not correlate with the datasheet

3.3.15 Temperature Sensor IC

1. Measure temperature sensor IC output voltage and compare with room temperature

Pass Condition: Voltage reading matches the graph on temperature sensor datasheet
Fail Condition: Voltage reading does not correlate with the datasheet

3.3.16 Constant Current Boost Converter (LED Driver)

1. Connect LED strips to the LED driver output
2. Power device
3. Enable LED Driver with MCU pin
4. Observe LED brightness

Pass Condition: LEDs turn on with desirable brightness level
Fail Condition: LEDs fail to turn properly/smoothly, or are too bright/dim and cannot be changed to the acceptable brightness level

3.3.17 Display Driver Circuitry

1. Flash MCU with firmware to grab an image from flash and drive it on the display
2. Power on device and execute display driver test code
3. Observe display

Pass Condition: Display flashes correct image in an acceptable time
Fail Condition: Display does not respond to the flashing procedure, image is unclear or in the wrong position.

3.3.18 Testing Summary

PCB Testing Results		
Tested Circuitry	**Results**	**Pass/ Fail**
Reverse polarity protection circuit	Works as intended	✔
Cell balancing IC	Untested	—
Undervoltage comparator	Undervoltage threshold works as intended, wrong hysteresis	—
Over-temperature comparator	Works as intended	✔

Overcharge discharge	Untested	—
Max power point tracking IC	Does not work reliably, specced boost diode smokes	✘
5V DC/DC converter & linear regulator	Works as intended	✔
SWD programming interface	Works as intended	✔
Microcontroller	Works as intended	✔
Cellular modem interface	Untested	—
Flash memory	Untested	—
USB to UART IC	Untested	—
Passive infrared motion sensor	Untested	—
Photoresistor	Works as intended	✔
Temperature sensor IC	Works as intended	✔
Constant current boost converter (LED driver)	Works as intended	✔
Display driver circuitry	The bottom part of the display does not work as expected	✘

Table 2. Summary of PCB Tests Results

3.4 Enclosure Testing

Objective: Validate the designed enclosure will withstand the Vancouver weather in accordance with **NFR4**.

Procedure:

1. Remove all electrical components from the enclosure frame.
2. Seal up all components of the enclosure (back-plate, aluminum sign, plexiglass, etc).
3. Conduct the necessary IP rating tests.
    a. Dust ingress rating test
    b. Moisture ingress rating test

Pass Condition: Enclosure withstands conditions rated for IP65 or higher (i.e. virtually no dust or water ingress).
Fail Condition: Enclosure fails to withstand conditions for IP65 or higher (i.e. dust or moisture found in the enclosure).

Results: Validation could not be completed due to cancellation of waterjet cutting service during COVID-19 outbreak

3.5 Integrated Testing

The full prototype after integration will be tested to see if every function works as expected.
Objective:
To determine if the prototype works as expected after integrating all parts. This test will be conducted indoors.
Procedures:

1. Repeat all the previous tests except the PCB tests. (Not doing PCB tests because PCBs are integrated inside the enclosure, thus unable to be tested)

Pass condition: All the previous tests pass.
Fail Condition: Any of the previous tests fails.
Results: Failed. Some of the previous tests failed.

4. Unit Testing during Development

This defines the tests we used to verify subcomponents during development using the manufacture development boards (e.g. STM32L496AGI6 cellular discovery board and . Doing so helped us identify where to look for bugs and tackle issues that arise efficiently. Once we got a component to work, we could rule out the possibility that the component is the source of issues.

4.1 Data Plan is Active

Objective:
To determine if the the telus internet plan and sim card are active and working.
Procedures:

1. Insert into a smart phone
2. Turn off wifi
3. Access a webpage

Pass condition: Able to access a requested webpage.
Fail Condition: No service in cellular signal status or cannot access request webpage.
Results: Passed.

4.2 Cellular Development Board Can Access Internet

Objective:
To determine if the source code given by ST for cellular dev board can access the internet with the data plan.
Procedures:

1. Open teraterm and configure the settings to receive data from the cellular dev board
2. Connect dev board to computer via micro usb cable
3. Compile ST source code and run on dev board
4. Use teraterm to ping google.com via the http echo application

Pass condition: google.come replies to the echo request.
Fail Condition: No reply to echo request or cannot connect and register to cellular network.
Results: Passed.

4.3 E-ink Goodisplay Hardware

Objective:
To determine the e-ink displays are not damaged in transit after purchase.
Procedures:

1. Connect display dev board to computer via micro usb cable

2. Convert any image to c array format (or use ours, we have monalisa)
3. Compile display source code and run on display dev board
4. Repeat with another image to see that display is image agnostic

Pass condition: Able to display image as expected
Fail Condition: Any imperfection in displaying the image
Results: Passed

4.4 Test Display Code Migration to Prototype Hardware

Objective:
To determine if display code migration is done correctly from display dev board to prototype hardware that uses a different family STM chips (F103 to L496 MCU).
Procedures:
1. Connect prototype that has display to computer
2. Use the same image as when testing on display dev board
3. Compile and run the migrated code

Pass condition: Same image shows up on prototype as on dev board
Fail Condition: Any difference between the two exists
Results: Failed. The upper half of the display was not behaving as expected. Also, the display was flipped around.

5. Conclusion

Validation is an important stage of product development. For the project, the majority of the validation procedures were interrupted due to the COVID-19 outbreak. Although the design portion of the project was completed, the validation stage was impacted the most. Within this document, we outlined each test with a procedure to assist with the development of the project.

Appendix A: Legacy Relevant Validation

This appendix is to provide information regarding validation tests that were completed through the previous year's project that relate to our iteration.

Weatherproofing Test

The deployed system off-the-shelf enclosure must be rated IP65 or higher to protect against rain, dust, wind and now.
Results: not yet tested.
Passed - No water present within enclosure.

Display Readability

A visual acuity test performed to determine whether the sign can be viewed in all conditions (including day and night scenarios) - test using a Snellen chart uploaded on display. The test was also completed to test readability with LEDs controlled by an ambient light sensor.
Results:
Passed - Readable as scoring 6/7.5 on a 6m Snellen chart when viewed at a distance of 6 meters.

Appendix B: Power Budget

To have an understanding of the power flow of the product, the following power budget was constructed to determine the power inflow and outflow found in Table 3 and 4 respectively.

	Power Req [W]	Total [W]	# of Units	Assumptions	Percentage
MCU	0.0026	0.0259	1	10.00%	0.27%
Display	0.4125	0.0825	1	5	43.49%
Cellular	0.0900	9	1	1.00%	9.49%
Sensors	0.0114	0.1136	1	10.00%	1.20%
Battery Management	0	0	1		0.00%
LED	0.4320	4.32	18	10.00%	45.55%
Batteries	0	0	0		0.00%
Total Power Consumption	0.948				100.00%
[Wh] per 2 Weeks	318.68				

Table 3. Power Inflow From Solar Panel and Batteries

	Power [Wh]	Total	#	Days	Percentage
Panel	262.234	18.731	1	14	62.79%
Batteries	155.4	12.95	12	14	37.21%
	0	0			0.00%
Total Power [Wh] - 2wk	417.634				100.00%

Table 4. Power Outflow From Sign Components

The data in Table 3 can be modified by altering the assumptions (percentage of time the component is on) which will update the budget.