# Atmospheric Vapor Extraction Device

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# Final Report

*Submitted towards partial fulfillment of the requirements for*
***Mechanical Engineering Design I – Fall 2015***

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# 1. Introduction

Our team wishes to put into practice an idea proposed by Chris Allender who is a biological sciences graduate student at NAU. Chris wishes to build a device that will help in the study of vapor extraction from the atmosphere. A constant supply of fresh water, coupled with an ever increasing human population has resulted an unprecedented fresh water shortage among developing nations as well as developed nations. Approximately two point five percent of the earth's water supplies are freshwater (National Geographic 2015). While approximately one percent of these freshwater is easily accessible, the remaining one half percent remains an untapped potential which contributes to the global clean water crisis.

Over extraction of freshwater from the world's reserves has resulted in unprecedented constraints on the supply of fresh water. Despite the numerous advances in the technologies that signify our modern world, such as desalination plants, the overall constraints in the freshwater supply is still a recurring issue among nations. Couple this with non-conservative habits that are common for most households, institutions, and business organizations, the need a for new methods of mining freshwater. As such, innovative techniques like vapor extraction possesses the ability to counteract some of the rising needs for water

# 2. Problem Statement

The client, Mr. Christopher J Allender, is looking for a device that is capable of extracting water from the atmosphere. Mr. Allender would like the device to collect data in order to find the optimal condition for which a maximum amount of water can be extracted. Though water vapor extraction devices do exist, there has not been enough research to find the optimal conditions. This project will serve as a teaching tool for future devices, and will possibly be used to aid communities that lack a potable water supply. The team's goal is to create a working atmospheric vapor extraction device that will be tested in different conditions, including: pressure, temperature, elevation, humidity, etc.

# 3. Course of Action

### Criteria

The following criteria were selected based on input from the client:

- **Size & Weight -** Size and weight were considered as criteria due to the constraint of having a portable device
- **Accuracy -** According to the client, the device should collect data, so the team considered accuracy as the criterion to drive the data logging.
- **Initial Cost -** The team decided that the initial cost was important based on the $1,000 budget.
- **Running Cost -** Running cost was considered based on the client's need for the device to run overnight.
- **Ease of Use -** Ease of Use was considered in order to minimize interaction with the device.
- **Reliability -** The team decided to make reliability a criterion for the refrigerator and the sensors/datalogger to guarantee consistent performance.

### Analytical Hierarchy Process

The Analytical Hierarchy Process was used to weigh the criteria numerically. This process uses a judgment scale (Appendix A) based on preference to score and weigh the criteria. The values are then normalized to determine the relative weight of each. Appendix B gives an example of this process and the resulting relative weights for each component are shown below in Table 1**.**

Table 1 - Criteria Relative Weights

<table>
<tr><th>Function</th><th colspan="8">Power Source</th></tr>
<tr><td>**Criteria**</td><td>**Size**</td><td colspan="2">**Weight**</td><td colspan="2">**Initial Cost**</td><td>**Running Cost**</td><td>**Reliability**</td><td>**Ease of Use**</td></tr>
<tr><td>**Relative Weight**</td><td>12%</td><td colspan="2">16%</td><td colspan="2">27%</td><td>12%</td><td>21%</td><td>12%</td></tr>
<tr><td>**Function**</td><td colspan="8">**Sensors / Logger**</td></tr>
<tr><td>**Criteria**</td><td>**Cost**</td><td colspan="4">**Reliability**</td><td colspan="2">**Accuracy**</td><td>**Ease of Use**</td></tr>
<tr><td>**Relative Weight**</td><td>13%</td><td colspan="4">29%</td><td colspan="2">52%</td><td>6%</td></tr>
<tr><td>**Function**</td><td colspan="8">**Refrigeration**</td></tr>
<tr><td>**Criteria**</td><td colspan="2">**Initial Cost**</td><td>**Weight**</td><td>**Running Cost**</td><td colspan="2">**Size**</td><td colspan="2">**Reliability**</td></tr>
<tr><td>**Relative Weight**</td><td colspan="2">27%</td><td>20%</td><td>15%</td><td colspan="2">13%</td><td colspan="2">25%</td></tr>
</table>

## Concept Generation

The team identified three main functions of the device. First, it needs to have a power source; second, it needs to have a condensing process; and lastly, it must have sensing equipment to detect and log the ambient weather conditions.

For power, the team considered the following options: outlet, generator, wind, and solar power. While sustainable power such as wind and solar is important, the reliability to run continuously will be taken into account. The condensing process cools the air by dissipating the heat. Many refrigeration devices are available on the market to do this. Other ideas included thermoelectric heating elements or the use of dry ice. The former being vastly inefficient for cooling the continuous flow of air, with the latter needing to be constantly restocked. As a result, research was focused on a refrigeration cycle. The final function is the sensing and data-logging component.  The team considered an Arduino-based, a Raspberry pi-based, and an all-in-one based system.  The Arduino and Raspberry pi rely on small, programmable CPU's that have the option of attaching sensors.  The all-in-one option is available to buy and is specifically designed to sense and store weather data.

**Decision Matrices**

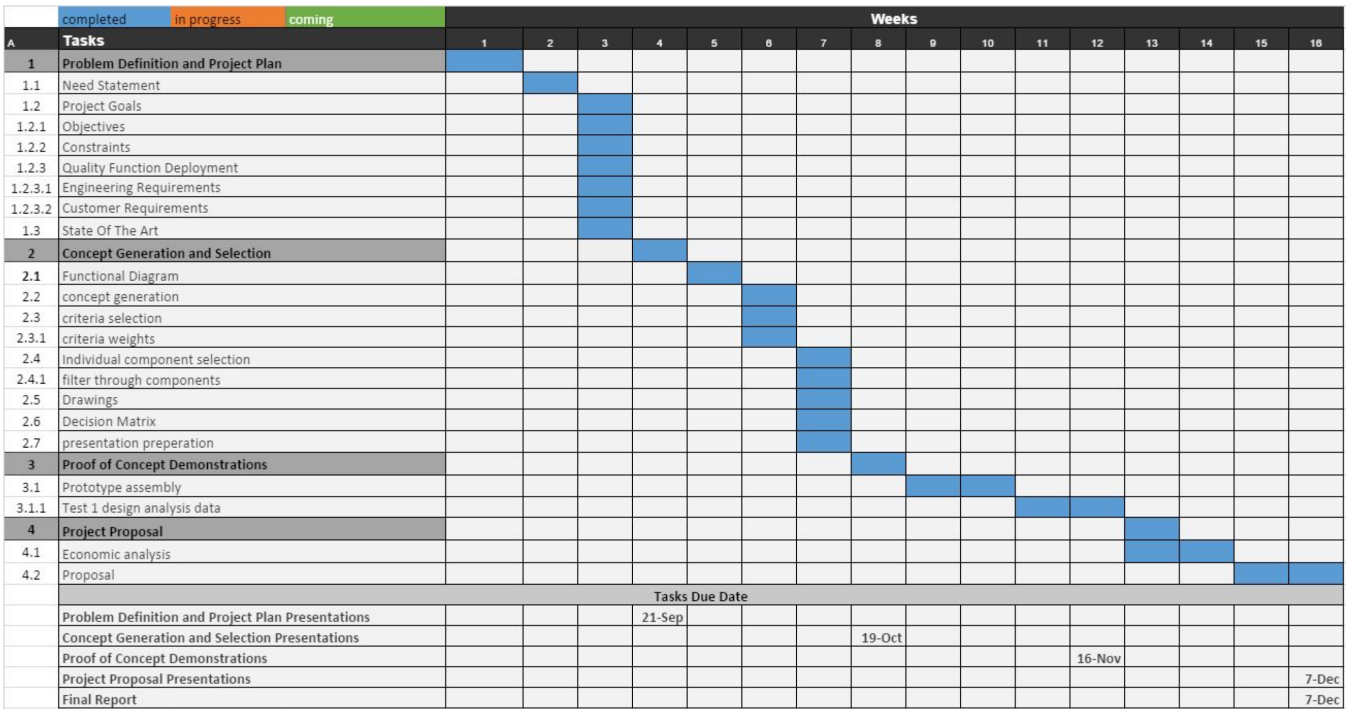
The decision matrix process, as recorded in Appendix C, ranked the following component options as the best:

- Power Source - Outlet
- Refrigeration - Koolatron P95 Travel Saver Cooler 52-Quart
- Sensors/Data Logging - Arduino DHT11

Typical city power via a power outlet was found to be the best option for power source based on its high reliability and low initial cost.  The Analytical Hierarchy Process has shown that these are the most important criteria to consider for power source.  Additionally, it is easily accessible and limits the size and weight of the device.  The Koolatron 52-Quart was found to be the best for this project based on its high Reliability and low cost.  For the electronics, all three options scored well, however, the Arduino was chosen to be the preferred program used for data logging due to the team's familiarity with the program.

## Progression Plan

As shown in the updated progression plan (Figure 2), 19 activities were completed by the 7th week. The plan comprises both parallel and sequential activities. The project started on September 1st and was scheduled to end on December 7th. The schedule was divided into time spans of one week per sequential or a set of parallel activities. However, this chart does not present dependency of the activities.



| | completed / in progress / coming | Weeks | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Tasks | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 1 | Problem Definition and Project Plan | | | | | | | | | | | | | | | | |
| 1.1 | Need Statement | | | | | | | | | | | | | | | | |
| 1.2 | Project Goals | | | | | | | | | | | | | | | | |
| 1.2.1 | Objectives | | | | | | | | | | | | | | | | |
| 1.2.2 | Constraints | | | | | | | | | | | | | | | | |
| 1.2.3 | Quality Function Deployment | | | | | | | | | | | | | | | | |
| 1.2.3.1 | Engineering Requirements | | | | | | | | | | | | | | | | |
| 1.2.3.2 | Customer Requirements | | | | | | | | | | | | | | | | |
| 1.3 | State Of The Art | | | | | | | | | | | | | | | | |
| 2 | Concept Generation and Selection | | | | | | | | | | | | | | | | |
| 2.1 | Functional Diagram | | | | | | | | | | | | | | | | |
| 2.2 | concept generation | | | | | | | | | | | | | | | | |
| 2.3 | criteria selection | | | | | | | | | | | | | | | | |
| 2.3.1 | criteria weights | | | | | | | | | | | | | | | | |
| 2.4 | Individual component selection | | | | | | | | | | | | | | | | |
| 2.4.1 | filter through components | | | | | | | | | | | | | | | | |
| 2.5 | Drawings | | | | | | | | | | | | | | | | |
| 2.6 | Decision Matrix | | | | | | | | | | | | | | | | |
| 2.7 | presentation preperation | | | | | | | | | | | | | | | | |
| 3 | Proof of Concept Demonstrations | | | | | | | | | | | | | | | | |
| 3.1 | Prototype assembly | | | | | | | | | | | | | | | | |
| 3.1.1 | Test 1 design analysis data | | | | | | | | | | | | | | | | |
| 4 | Project Proposal | | | | | | | | | | | | | | | | |
| 4.1 | Economic analysis | | | | | | | | | | | | | | | | |
| 4.2 | Proposal | | | | | | | | | | | | | | | | |
| | Tasks Due Date | | | | | | | | | | | | | | | | |
| | Problem Definition and Project Plan Presentations | | | | 21-Sep | | | | | | | | | | | | |
| | Concept Generation and Selection Presentations | | | | | | | | 19-Oct | | | | | | | | |
| | Proof of Concept Demonstrations | | | | | | | | | | | | 16-Nov | | | | |
| | Project Proposal Presentations | | | | | | | | | | | | | | | | 7-Dec |
| | Final Report | | | | | | | | | | | | | | | | 7-Dec |

Figure 1 - Gantt Chart

# 4. Sensors

Weather sensors will be used to evaluate the conditions that the device is operating in. The main concern of the team is the dew point of the air at any given time. The dew point, is how many degrees the air needs to be cooled in order to start condensing water. The main factors in the dew point are the ambient temperature, the relative humidity and the pressure.

In order to get accurate data about the device, the placement of multiple sensors is important. The bare minimum would to have a sensor at the input and the output. The input would read the ambient conditions, while the output would be able to track the temperature difference, and a rough estimate of water extracted. There is also the option of placing sensors inside the cooler itself to find temperature at certain points inside the cooler.

Currently, the team own two different models of sensors DHT-11's and a BMT 180. The DHT's are able to find temperature and humidity, while the BMT can detect temperature, pressure and altitude. The current plan is to use primarily the DHT's, because temperature and humidity are the most important in our research. The atmospheric pressure at one location will most likely not change wildly. That being said, using a BMT to find a more accurate dew point, as well as having more data to store is worth the effort and space of adding another sensor.

One of the main functions of these sensors will be to find the dew point at any given time, and decide if the device will be able to condense a sufficient amount of water to be considered efficient. If the conditions ever get to such that the cooler cannot cool the air quick enough, or would not extract much water, the controller will shut off of slow down to have a better efficiency. With our current design of three fans pumping air through the system we can control how many, if any of these fans are turned on. The team will be using an Arduino Uno to manage the sensors, and power the fans.

The Arduino can output 3.3V and 5V, which is sufficient to power the 5V computer fans and the sensors which run off of 5V also. To add even more variability to the fans, they could also be run off of the 3.3V so they run at a slower speed if that is desired. A few problems with this is, how the Arduino is powered, through the wall outlet or a battery pack, and whether the Arduino can handle the power draw of all the fans and sensors.

# 5. Design

For the project , three coolers were taken into consideration. The first option Igloo 40-Quart, a cooler to store food and beverages of maximum 40 quarts, was rejected because there were negative reviews published about the product. The second option, Dometic 15-quart, a cooling facility that can be used at picnics, dorms etc, was rejected due to its capacity issues as it is small in size. Lastly, Koolatron 52 - Qaurt was chosen for the course of this project. It was the best product to fit the needs of the project team.

Koolatron, a cooler was chosen which has some needed features. The appliance is capable of cooling 40 degrees Fahrenheit below the surroundings temperature. It is light in weight and weighs about 17.4 pounds. The appliance has good size for a portable refrigerator measuring 20 x 15.5 x 20 inches. It has a 12V outlet fitted with 120V AC adapter.

The traditional lid well be replaced by a customized Styrofoam lid of 3 inches. The system will use the concept of ambient air cycle. The lid will have a piping system. The input pipe will ensure ambient air input and the output pipe will release the dry air outside. Beneath the surface of the lid, fans will be introduced to circulate the air.

There will be a combination of fans that will be installed under the lid. The specifications of the fans will be according to the atmospheric conditions of the area. The speed of the fan will be controlled and adjusted by the arduino which is a microcontroller based kit used as a sensor. The ideal level of air flow to be maintained by the device will be 57.67 CFM and the fan speed will be around 1500 revolutions per minute (RPM) with a upper and lower bound of 10%. The fans will be connected to the funnel which in turn will be linked to tube assembly.

# 6. Manufacturing

In order to manufacture the cooling channels 1/64'' aluminum sheet metal will be used. The team decided aluminum was the best choice to make the channels because of its low weight, resistance to corrosion, affordability, and flexibility. Once we have cut out all of the sheet metal shapes, a spot welder will be used to connect the pieces together. Because there will be rough edges on all of the parts cut out and corrosion will form from those rough edges, a water repellent spray could be used to reduce corrosion. From the Solidworks drawing shown below the team was able to approximate the amount of aluminum needed to create the channels.

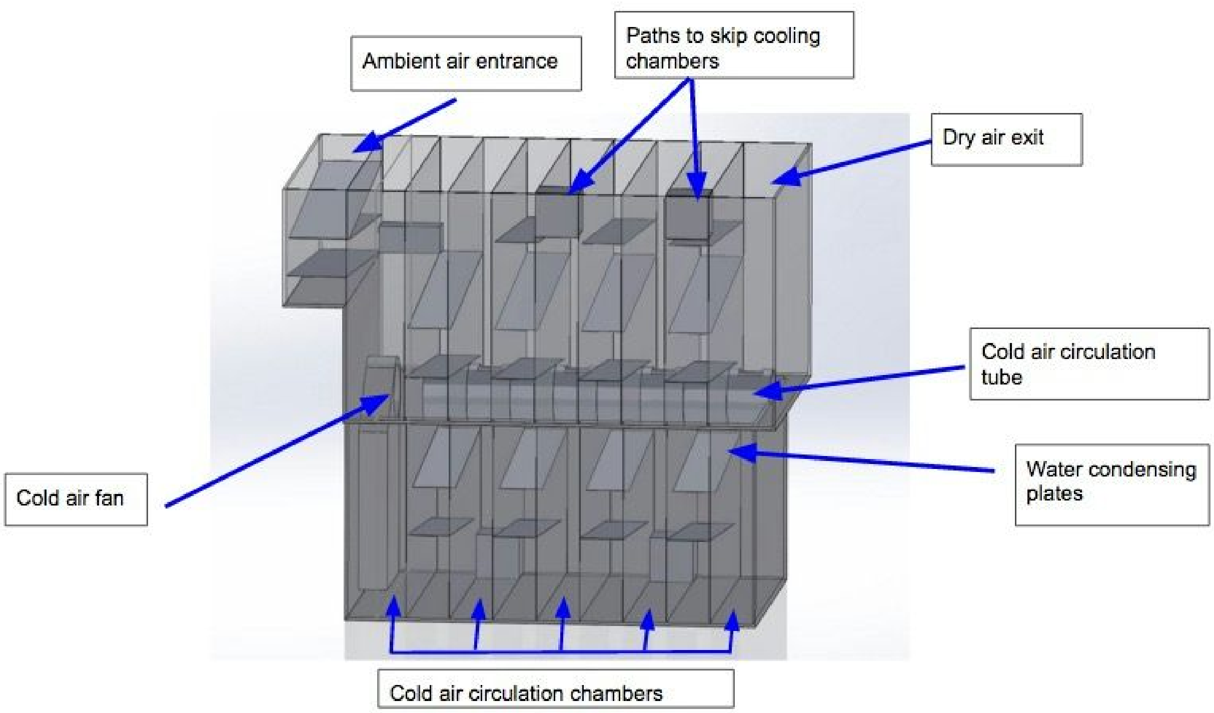



Figure 2 : Cooling Channels

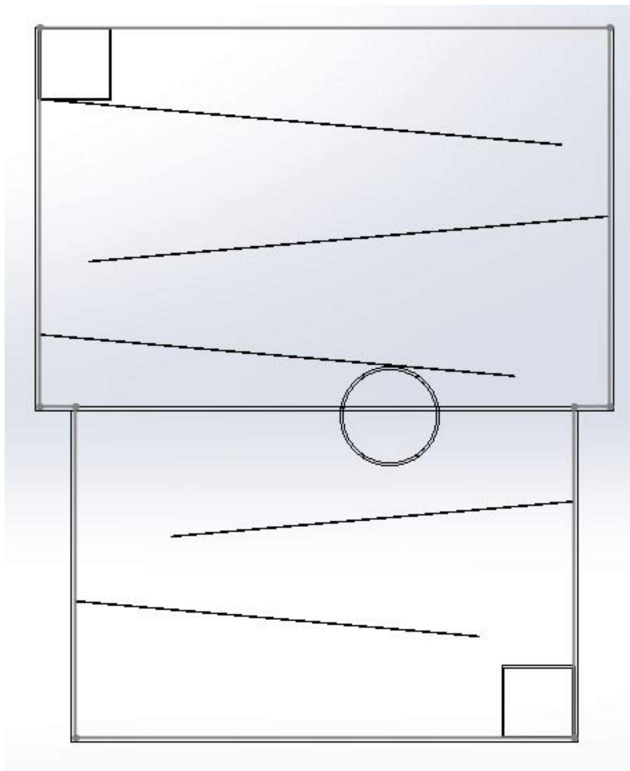


Figure 3 : Side view of channels

The total area of sheet metal is 1,734 in^2 with a volume of 27.093 in^3. We will also need to purchase an aluminum tube with a 2 inch diameter that is 1 foot in length. The tube will help to direct the cold air produced by the fan to the cooling chambers, these cooling chambers will cool the metal from one side while the warmer ambient air from the outside will circulate through from the other side. This change of temperature will cause the effect of condensation on the metal. After enough water molecules have formed on the metal they will begin to drip down the condensing plates until reaching the bottom of the cooler where the water will collect.

The team has decided on three different options to remove the water from the cooler. A decision has not been yet however because testing is needed to decide on the best option. The first option is to attach a handle to the top of the channel assembly and once there is enough water collected the user will simply remove the assembly and pour the water into whatever is desired. The second option is to buy a water pump that will pump the water out of the cooler. The pump will be turned on and off based on the water levels in the cooler. The last option is to drill a hole into the bottom of the cooler fitted with a manual valve. For the prototype the first option will be used progressing to the second option.

# 7. Bill of Materials

Table 2 : Bill of Materials

| Part # | Part Name | Qty. | Price |
|---|---|---|---|
| **1** | Portable Refrigerator [1] | 1 | $169 |
| **2** | Aluminum Sheets (3ft x 3ft) [2] | 2 | $42 |
| **3** | Arduino [3] | 1 | $70 |
| **4** | Fan (3 pack) [1] | 1 | $11 |
| **5** | Styrofoam Insulating Lid [2] | 1 | $25 |
| **6** | Pipe (PVC 1.5in diameter) [2] | 1 | $7 |
| **7** | Aluminum Pipe (2in diameter) [2] | 1 | $16 |
| | | | **Total: $324** |

Besides the main components, the team decided to purchase aluminum sheets, fans, a styrofoam insulating lid, and pipes. The aluminum sheet will be used in the manufacturing of the cooling chambers, the styrofoam lid will be used as an insulated top, in which we can drill holes through.

The inlet and outlet will both be on the styrofoam lid.  The fans will be placed near the inlet, in order to push air through.

We decided to purchase the aluminum sheets, styrofoam lid, and pipes from home depot due to its convenience and low price.  The styrofoam lid and pipes come in large quantities, which will allow us the leisure to try different designs and ideas.  Since,computer fans proved to be sufficient, we decided to purchase a 3-pack on amazon for $11.   For this project no labor is being considered because it is all being done in house.

# 8. Conclusion

Water is a vital resource to life, and though almost 71% of the world is composed of water, only 3% is considered to be potable water.  The purpose of this project is to extract water from the atmosphere, an untapped resource.  More specifically, our goal is to design an atmospheric water extraction device, in order to determine if extracting water from air is a viable option in arid environments.  The design has three main components:  cooling, power, and data logging.  For each of these components a decision matrix was used, based on weights acquired from the hierarchical process.  For the cooling, the team decided to use the Koolatron 52-quart.  For power, the team decided an outlet would best meet the needs of this project.  Finally, in terms of data logging, the team decided that an Arduino would be the best choice.  In addition to the main components, the team plans on purchasing aluminum sheets, fans, a styrofoam insulating lid, and pipes.  The aluminum sheets will be welded and placed inside of the refrigerator, in which it will direct airflow.  The pipes and fans will be used for the inlet and outlet of the design.  The fans purpose is to push air through the inlet and the cooling chambers.  Finally, the insulating lid will be used as the top platform in which we can drill holes through.  The next step to this project is to begin manufacturing the cooling chambers.

# 9. References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## APPENDIX A - Scales

Table A1 - Judgement of Preference

| Judgement of Preference | |
|---|---|
| **Judgement of Preference** | **Numerical Rating** |
| Extremely preferred | 9 |
| Very strongly preferred | 7 |
| Strongly preferred | 5 |
| Moderately preferred | 3 |
| Equally preferred | 1 |

Table A2 - Refrigeration Scale

| Refrigeration Scale | | | | |
|---|---|---|---|---|
| **Performance Level** | **Value** | **Cost ($)** | **Running Cost (W)** | **Weight (lbs)** |
| Perfect | 10 | 0 | 0 | 0 |
| Excellent | 9 | 100 | 100 | 10 |
| Very Good | 8 | 200 | 200 | 20 |
| Good | 7 | 300 | 300 | 30 |
| Satisfactory | 6 | 400 | 400 | 40 |
| Adequate | 5 | 500 | 500 | 50 |
| Tolerable | 4 | 600 | 600 | 60 |
| Poor | 3 | 700 | 700 | 70 |
| Very Poor | 2 | 800 | 800 | 80 |
| Inadequate | 1 | 900 | 900 | 90 |
| Useless | 0 | 1000 | 1000 | 100 |

## APPENDIX A - Scales

Table A3 - Power & Data Logging Scale

| Power & Data Logging Scale | |
|---|---|
| **Performance Level** | **Value** |
| Perfect | 10 |
| Excellent | 9 |
| Very Good | 8 |
| Good | 7 |
| Satisfactory | 6 |
| Adequate | 5 |
| Tolerable | 4 |
| Poor | 3 |
| Very Poor | 2 |
| Inadequate | 1 |
| Useless | 0 |

## APPENDIX B - Analytical Hierarchy Process Example

Table B1 - Power Source Criteria Weights

| Power Source | | | | | | |
|---|---|---|---|---|---|---|
| | **Size** | **Weight** | **Initial Cost** | **Running Cost** | **Reliability** | **Ease of Use** |
| **Size** | 1 | 1/3 | 1/5 | 1/5 | 1/7 | 5 |
| **Weight** | 3 | 1 | 1/5 | 1/5 | 1/7 | 3 |
| **Initial Cost** | 5 | 5 | 1 | 3 | 3 | 5 |
| **Running Cost** | 5 | 5 | 1/3 | 1 | 1/3 | 3 |
| **Reliability** | 7 | 7 | 1/3 | 3 | 1 | 3 |
| **Ease of Use** | 1/5 | 1/3 | 1/5 | 1/3 | 1/3 | 1 |

Table B1 - Power Source Criteria Relative Weights

| Power Source | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Size** | **Weight** | **Initial Cost** | **Running Cost** | **Reliability** | **Ease of Use** | **Rel. Weight** |
| **Size** | 0.047 | 0.018 | 0.088 | 0.026 | 0.029 | 0.250 | **8%** |
| **Weight** | 0.142 | 0.054 | 0.088 | 0.026 | 0.029 | 0.150 | **8%** |
| **Initial Cost** | 0.236 | 0.268 | 0.441 | 0.388 | 0.606 | 0.250 | **35%** |
| **Running Cost** | 0.236 | 0.268 | 0.147 | 0.129 | 0.067 | 0.150 | **17%** |
| **Reliability** | 0.330 | 0.375 | 0.147 | 0.388 | 0.202 | 0.150 | **27%** |
| **Ease of Use** | 0.009 | 0.018 | 0.088 | 0.043 | 0.067 | 0.050 | **5%** |

## APPENDIX C - Decision Matrices

Table C1 - Power Source Decision Matrix

| Power Source | | | | | |
|---|---|---|---|---|---|
| | **Wind** | **Solar Panels** | **Generator** | **Outlet** | **Battery** |
| **Size** | 0.33 | 0.57 | 0.51 | 1.02 | 0.87 |
| **Weight** | 0.48 | 0.68 | 0.40 | 1.28 | 0.92 |
| **Initial cost** | 1.15 | 1.15 | 1.15 | 2.16 | 1.49 |
| **Running cost** | 0.78 | 0.90 | 0.39 | 0.69 | 0.72 |
| **Reliability** | 0.84 | 1.16 | 1.26 | 1.42 | 1.05 |
| **Ease of use** | 0.39 | 0.57 | 0.63 | 0.96 | 0.90 |
| **Total** | 3.97 | 5.02 | 4.34 | 7.53 | 5.95 |

Table C2 - Refrigeration Decision Matrix

| Refrigeration | | | |
|---|---|---|---|
| | **True 884621 1/6 HP - 115V** | **RCA** | **Frigidaire** |
| **Cost** | 1.77 | 2.93 | 2.71 |
| **Weight** | 1.16 | 1.11 | 0.87 |
| **Coefficient of Performance** | 4.38 | 4.65 | 1.28 |
| **Total** | 7.30 | 8.70 | 4.85 |

Table C3 - Data Logging Decision Matrix

| Data Logging | | | |
|---|---|---|---|
| | **Arduino Based** | **Raspberry Pi Based** | **All-in-One** |
| **Cost** | 0.91 | 0.78 | 0.65 |
| **Reliability** | 2.03 | 1.45 | 1.74 |
| **Accuracy** | 3.64 | 3.64 | 4.16 |
| **Ease of Use** | 0.54 | 0.24 | 0.24 |
| **Total** | 7.12 | 6.11 | 6.79 |