four day time period to evaluate the results of a cartridge's ability to reach the wet bulb temperature over a longer time scale. With the described experimental set up of the wind tunnel, there seemed to be little effect on the zeer-pot chamber temperature over a larger time scale.

From this final experiment, it was recommended to test a larger scale model that could better simulate the effect of the zeer-pot structure over a larger time scale. In addition to this, it was recommended to use lower fan speeds as a result of the minimal effect of this variation and the desire to consume as little electricity as possible. It was also recommended that a wall thickness of 2.5 to 5 cm be used to use less resources than the 7.5 cm wall thickness but still obtain an adequate amount of insulation.

2) Hydraulic/ Structural Model

Once the structural model was successfully built, the design challenges previously mentioned were able to be addressed.

a) Diagram and Explanation of the Hydraulic/Structural Model

The prototype was designed to be the same height as that which would be used in the final design. It consisted of a basic frame and four panels. The panels were attached to the frame via hinges. This allowed the panels to be removed if there was ever a need to do so. Metal mesh was welded to the inside of the removable panels and the inside of the frame. Fabric was then inlaid between the mesh, creating a space for the sand. The figure below shows a top down view of the aforementioned wall.

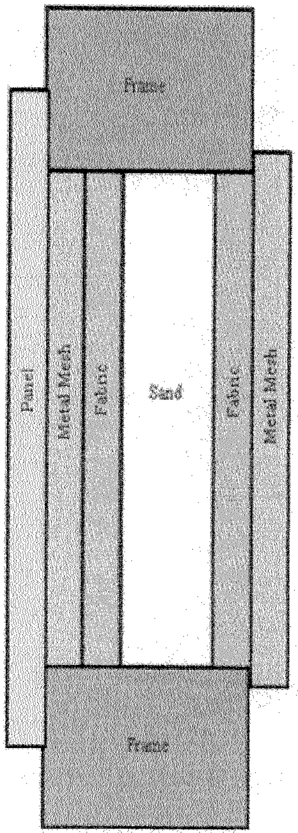

Figure 17. Top down view of the structure prototype wall.

Two of the side panels were the same width as a panel would be in the final design. In an effort to restrict the size, the last two panels were half the width of the first two. The idea was that if this model proved to be functional then the final design would also be functional. This was true because the only difference between this model and the final design is to add more panels to achieve the necessary length. The figures below show a CAD model of the basic structure of this prototype and a CAD model of the basic structure of the final design.

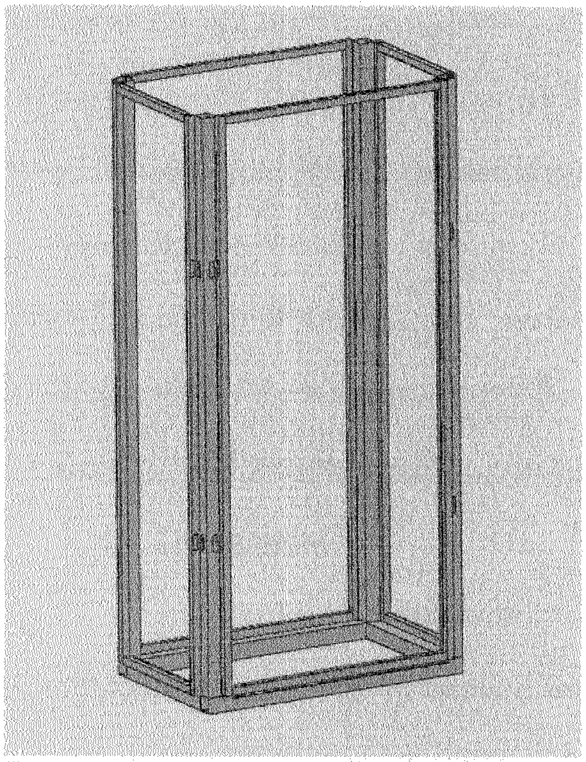

Figure 18. CAD model of the structural prototype.

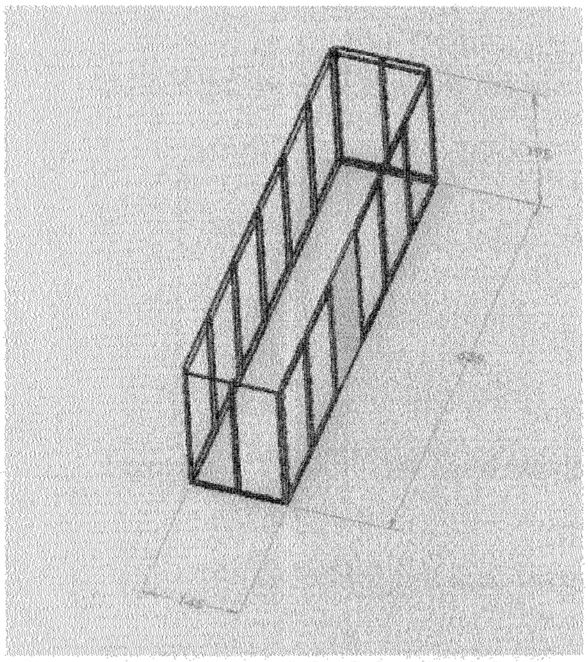

Figure 19. CAD model of the final design.

It can be seen that the final design is very similar to the structural prototype. The only difference is the addition of panels to create a space that is large enough to house the required amount of potatoes. There are a few other parts that make up the structural prototype. A piece of plywood with insulation attached to it serves as the roof. A five gallon bucket with a hose attached through a valve serves as the entrance for water into the system. A gutter system at the base of prototype exists to prevent water from gaining entrance into the center of the prototype. To be able to see if this system was capable of wetting a wall, one of the half length panels was made of polycarbonate. This allowed a full length view of the sand inside the wall.

b) Experimental Results and Recommendations for Final Solution

(1) Deformation

One of the first concerns that were voiced was how much force the sand would exert laterally on the metal mesh that was confining it. It was predicted that this force would cause the metal to deform and it was prudent to determine to what extent the mesh would deform. Figure 24 below shows the cross-section of a wall in the zeer-pot and how the sand reacted when poured into the wall.

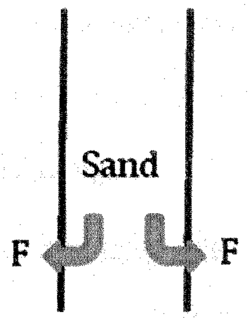

Figure 24. Forces from sand being exerted on metal mesh.

It was decided that four different types of metal mesh would be used on the structural model. The metal meshes differed in gap sizing which was directly related to how rigid they were. Of the four different meshes used, three were expanded metal mesh with diamond shaped gaps. One had a gap length of 0.5 inches and the other two had a length of 0.25 inches. The separating factor between the two similar length meshes was that the diamond gap was raised and not flat, making for a more rigid design. Concrete mesh was used for the final panel. The concrete mesh had a square gap size of 4 in. by 4 in. In the case of the concrete mesh, steel wire was pushed through the fabric and sand to connect both meshes at various intervals for support.

Once the sand was poured into each side, the amount of deformation was seen. All of the expanded meshes had limited deformation. As predicted the larger the gap length, the higher the deformation was. This was also true for the half length walls compared to the full length walls. The full length walls had more sand confined within, creating a larger outward force, which translated to a greater deformation. The big surprise of the study was the fact that the concrete mesh with reinforcing ties had a low deformation. The concrete mesh was purchased for nearly ten times less than the other metal meshes. Its larger gap size also meant that more evaporation could take place at the boundary. Both of these facts gave the concrete mesh an overwhelming margin of victory to be part of the final design.

(2) Water System

The addition and removal of water to and from the system was also a vital part of the structural prototype. The walls of the structure must be saturated so that evaporative cooling can occur. The source of water for the structural prototype starts with a five gallon bucket that sits atop of it. A valve was situated at the bottom of the bucket. When the valve was opened, water moved into the attached hose. The hose was fed around the perimeter of the prototype directly above the sand. Several holes were drilled into the hose that allowed water to escape. This water would then filter down through the wall, saturating the entire section. Figure 25 below lays out this process.

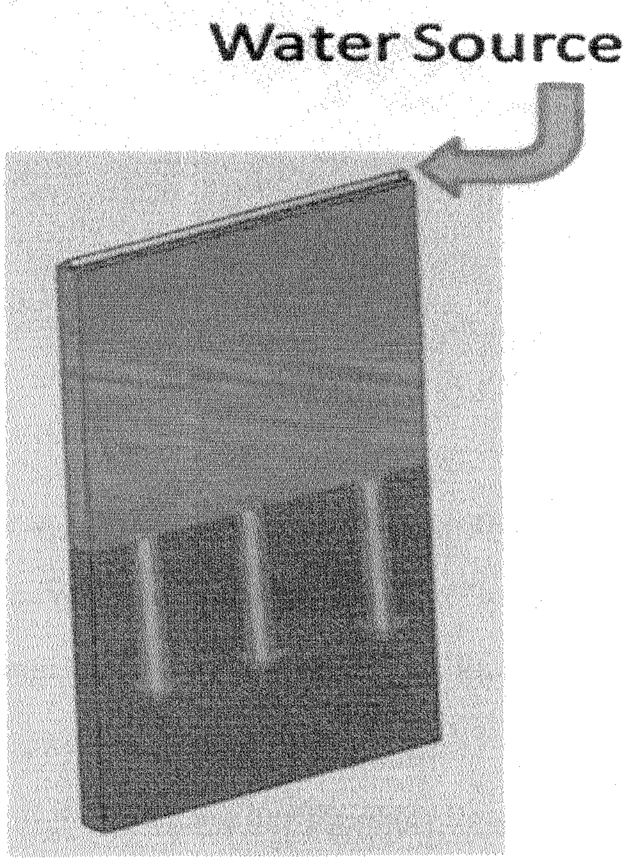

Figure 25. Saturation of sand in wall.

A water removal system was also part of the structural prototype. A piece of sheet metal was angled and then fixed inside the middle of the wall at the very bottom. The purpose of this piece was to force the water towards the outside. A second piece of sheet metal was fixed to the outside of the frame below the panel which would divert the water exiting from the wall into a gutter laid below it. Figure 26 below shows how the water is directed in part to the pieces of sheet metal. Through testing, it was seen that this setup successfully moved water away from the central volume.

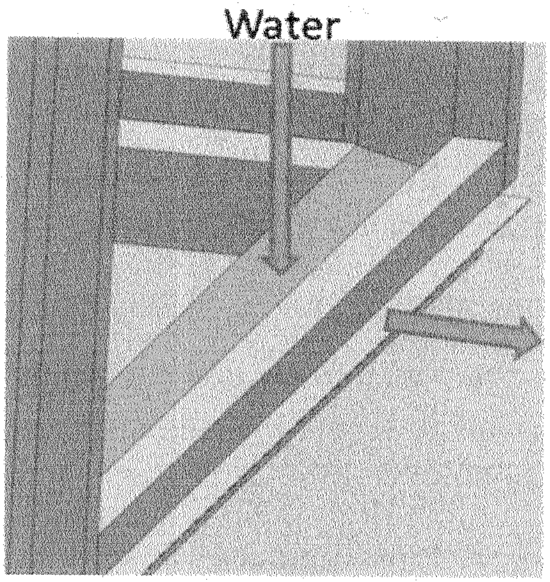

Figure 26. Flow of water through wall

The final part of the water system was the piece of polycarbonate that allowed one to see the sand being wetted. It does not allow a cross section view of the wall so it is impossible to see if the entire cross section was being wetted evenly. However, through use, we were able to see the water travel down the entire wall.

(3) Temperature and Humidity Readings

The primary function of the structural prototype was not to gain internal storage conditions like temperature and humidity, but rather to confirm the structural integrity of the design and the functionality of the water delivery system. Although this is true, some internal storage conditions data was collected. The prototype cools solely by the method of evaporative cooling. This meant that if our prototype was 100% efficient, the internal temperature would correspond to the wet bulb temperature. It was known that this would be nearly impossible to achieve since the side with the polycarbonate would not allow evaporation. It was also idealized that the inside would reach a relative humidity of 100%.

Figure 27 depicts the temperature drop from ambient to the temperature measured in the prototype. It also shows the wet bulb temperature which would be the minimum temperature the prototype could attain. The measurements were taken at various times over a three day period.

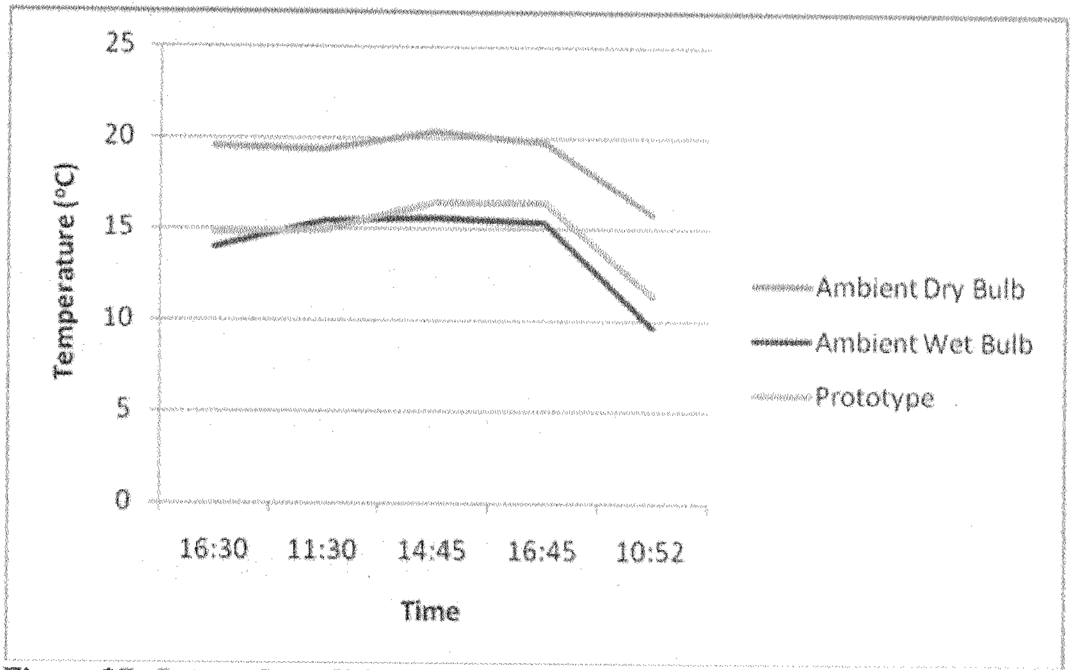

Figure 27. Internal conditions data (ambient dry bulb, ambient wet bulb, and internal temperature) of the structural/hydraulic prototype.

The graph shows that the temperature in the prototype was close to the ambient wet bulb. From these five samples, it was determined that the prototype was functioning with an efficiency of 85%. This was a remarkable figure considering the fact that one wall was not cooling but rather functioned as an insulator. The second variable that was measured was relative humidity. Figure 28 below shows the relative humidity inside the prototype as well as the relative humidity surrounding the prototype.

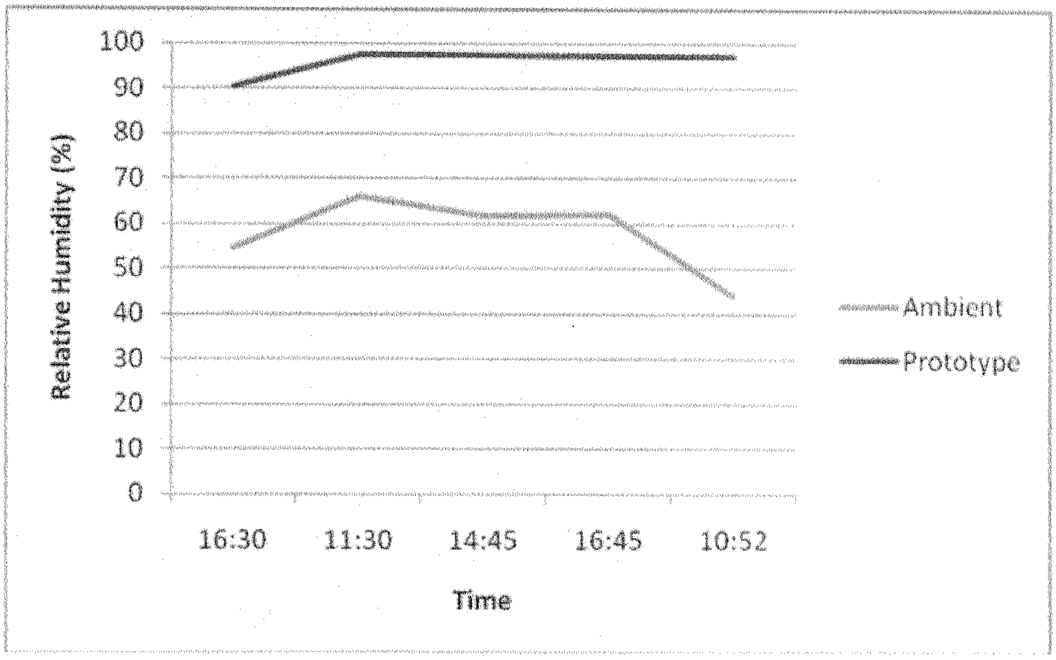

Figure 28. Relative humidity data from the structural/hydraulic model

The graph shows that through evaporative cooling the prototype was almost able to maintain a relative humidity of 100%. The experimental testing that took place inside the structural prototype provided results that corresponded well to what was originally predicted. The details of this examination are found in Appendix 8 of this report.

(4) Recommendations

Through the construction of the structural prototype, there were many successes and many failures. These failures were valuable lessons that contributed to design changes. Due to time restrictions, not all of these changes have been implemented into the structural prototype or final design. The first recommendation would be to use hinges that had a larger clearance fit. Upon welding the mesh to the panel, the steel began to minutely warp. This small difference made it difficult, with the hinges that were installed, to place the panel on the frame and also to remove it from the frame.

The next recommendation involves the process of welding the concrete mesh to the panels and to the frame. It should be welded to both so that when the panel is attached to the frame, the meshes should be aligned. If this is not the case, the metal ties connecting both of the meshes traverse the fabric at an angle instead of being perpendicular to the fabric. The ties, when angled through the fabric, can develop large holes in the fabric where sand can escape.

A final change deals with the hose placed on the top of the zeer-pot spanning the perimeter. In the structural prototype, the hose sits nicely on the sand until it has to traverse a steel frame post where it is forced to bend and go over the post. In the final design, a slot should be cut into the top of every vertical frame post so the hose can lay flat. These changes should be implemented to create a better final product.

Part III – The Final Recommended Solution

A) Explanation of Supporting Data and its Affect on the Final Solution

The design of the final structure utilizes and combines the results of the wind tunnel testing trials, the full scale hydraulic model, the needs of the customer, as well as the availability of materials in and around the village of Borko. Because a main constraint on site will be the availability of materials, the testing that was performed at St. Thomas was done to assess and predict the performance of the bounds of certain variables that could be expanded or contracted. For example, the wind tunnel performed calculations on 2.5 and 7.5 centimeter thick cartridges. The availability of materials near the village will be able to obtain a thickness anywhere within that range. The final thickness of the walls will be 5 centimeters, which was tested in the hydraulic model because it will allow for adequate water containment and better insulation than the 2.5 centimeter thickness. Since the 1.5 ounce fabric will be more robust that the 1 ounce fabric without significant affect on the performance of the structure, the 1.5 ounce fabric will be used in the walls built for the structure in Borko.

Natural convection through the existing building or use of the low speed setting on the fans will be used to aid in the evaporation process. The fans will be used should the speed of the air in the building from natural convection be less than 1.5 m/s, the lowest speed on the fan. With the data obtained from the hydraulic/structural model, the 4 inch contcrete mesh will be used in the final design. When combined with the other chosen variables, this design should obtain an evaporative cooling efficiency between 70 and 80%. According to the daily local environment NASA data in the technical model, this will achieve temperatures below 15° C, and relative humidity levels between 90 and 100%. In summary, this will satisfy the seed potato storage environment requirements outline by the customers in Mali.

In terms of power generation, there are several recommendations that can and should be made for the final solution. Currently the design calls for power sinks (portions of the design that will require power) of one water pump and three variable speed box fans. The effect of the evaporative cooling experienced while testing the mass transfer model was fairly consistent regardless of the fan speed. In other words, the relative humidity experienced in the zeer-pot chamber did not fluctuate greatly between low, medium, and high fan speeds. Concurrently, when the larger hydraulic model was tested for temperature drops and humidity increases, there were no fans blown on the model. The wind source was simply the chimney effect from convection from the interior to the exterior of the building. Air was blown from a high pressure area to a low pressure area without the aid of any electricity. The wind speeds experienced through this method of air flow were within the range of known wind speeds from the box fans.

With this knowledge in hand, it seems like the best idea would be to use natural ventilation from convection in Borko on the final design. Only if the relative humidity increases and temperature drops are not great enough should fans be employed. In essence, the initial final design should be to only have a water pump and no fans. If the results of the zeer-pot on site are not good enough, fans can be added. This will save great amounts of power (80W per fan, 240W total) as well as cost ($1342) from the fans, the inverter, extra solar panels, and extra batteries needed to run the fans. See Appendix 5 for Power System Block Diagram.

The controls that will be utilized on the final design are mostly mechanical. If the effect of the evaporative cooling is not great enough and fans are needed, they will be controlled simple manual speed adjustments. If no fans are needed, there will be not controls necessary. To control the amount of charge the solar panels deliver to the battery bank, a simple charge controller will be used. Finally, the water pump will be turned on and off by a simple float switch that is contained within the water tower (see Appendix 10 for detailed description).

B) Final Construction Plan Summary

Through design and the testing of prototypes, a final design was produced. The final design consists of building two evaporative cooling zeer-pots in a room in a building that was deemed usable for this purpose. The main structure of the zeer pot will be built out of steel and covered with an oil based paint to prevent corrosion. The mesh on the panels and frame will be similar to concrete mesh which has a large gap size. This will promote the evaporation process. The mesh will be reinforced with metal ties connecting the two sides. The gutter system will be similar to what was used in the structural prototype and is described in Appendix 10. Water will gain entry through hoses that lie on the sand at the top of the zeer pots. This water source will be provided from a nearby water tower. As for the storage of potatoes inside the zeer pots, they will be suspended from racks in porous bags. All detailed drawings and building processes are contained in Appendix 9 and Appendix 10 respectively.