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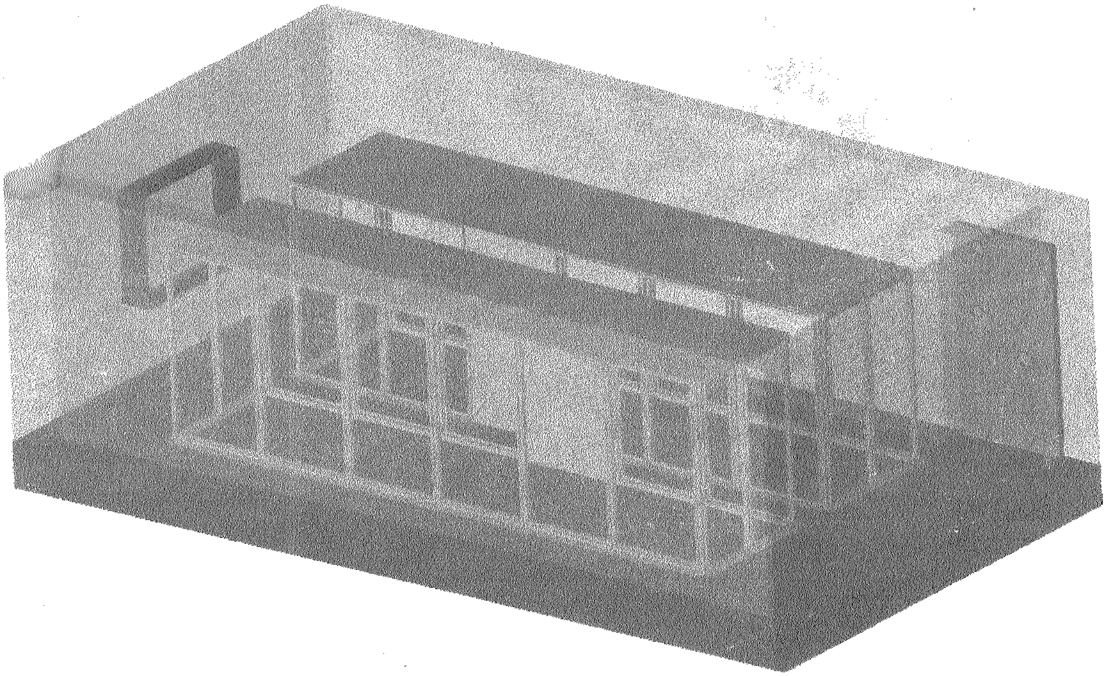
A COMPREHENSIVE EXPERIMENTAL, ANALYTICAL, AND NUMERICAL INVESTIGATION OF SEED POTATO STORAGE IN BORKO, MALI



May 12, 2010 | University of St. Thomas, St. Paul, Minnesota

Abstract

The Mali Agribusiness Center in conjunction with the University of St. Thomas assisted the village of Borko, Mali to establish a seed potato crop. Other crops this village currently raises (onions, garlic, and tobacco) are stored in the local, hot, and dry environment. Conversely, seed potatoes need to be stored in a cold, humid environment. The villagers in Borko needed a creative cooling method that was economically efficient for their new seed potato crop. To tackle this difficult problem, the project was divided into major categories including cooling, power generation, controls, and structural components. Within each sub-section of the project, brainstorming was conducted to unearth all possible solutions.

During January of 2010, three members of the University of St. Thomas team traveled to Borko, Mali to conduct interviews with the villagers to see how their preferences would align with possible solutions. Ultimately, an entirely passive cooling system was selected to minimize cost while maintaining minimum levels of cooling and humidity necessary for healthy seed potato storage. This evaporative cooler is unique in that it will utilize steel for structural integrity and steel mesh to maximize surface area for cooling. A water pump and several fans (if necessary) will be powered by a small array of solar panels and batteries. All materials needed for successful construction are available locally. As shown by the collected data, the design selected is as efficient as traditionally designed evaporative coolers while maximizing the surface area for cooling.

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Part I – Introduction

A) Problem Background

1) Customer Design Requirements

When the problem was first handed to the University of St. Thomas engineering design team, there was a list of specifics the customer requested to be included in the final design. In no particular order, the customer's design requests were: to use minimal energy, to be affordable, to be robust, to be quiet, to need minimal user intervention (autonomous), to be culturally acceptable, to be safe and non-toxic, to be easy to use, to use water efficiently, and finally, to fulfill all of the necessary requirements for healthy seed potato storage.

In order to focus time, energy, and monetary resources more effectively, this list of customer requests was then ranked in order of importance. The list in this order was: 1) Safe and non-toxic, 2) Minimal potato loss from disease during storage, 3) Affordable, 4) Robust, 5) Minimal user intervention, 6) Low energy, 7) Use water efficiently, 8) Reproducible, 9) Culturally acceptable, and 10) Quiet.

A list of design metrics was generated from this ranked list of customer requests. By correlating the design metrics with the design requests, a weighting system was used to discover what design metrics would achieve the customer's requests most effectively. In other words, where would time and energy best be spent on this project. Figure 1 displays the weighted importance of the design metrics.

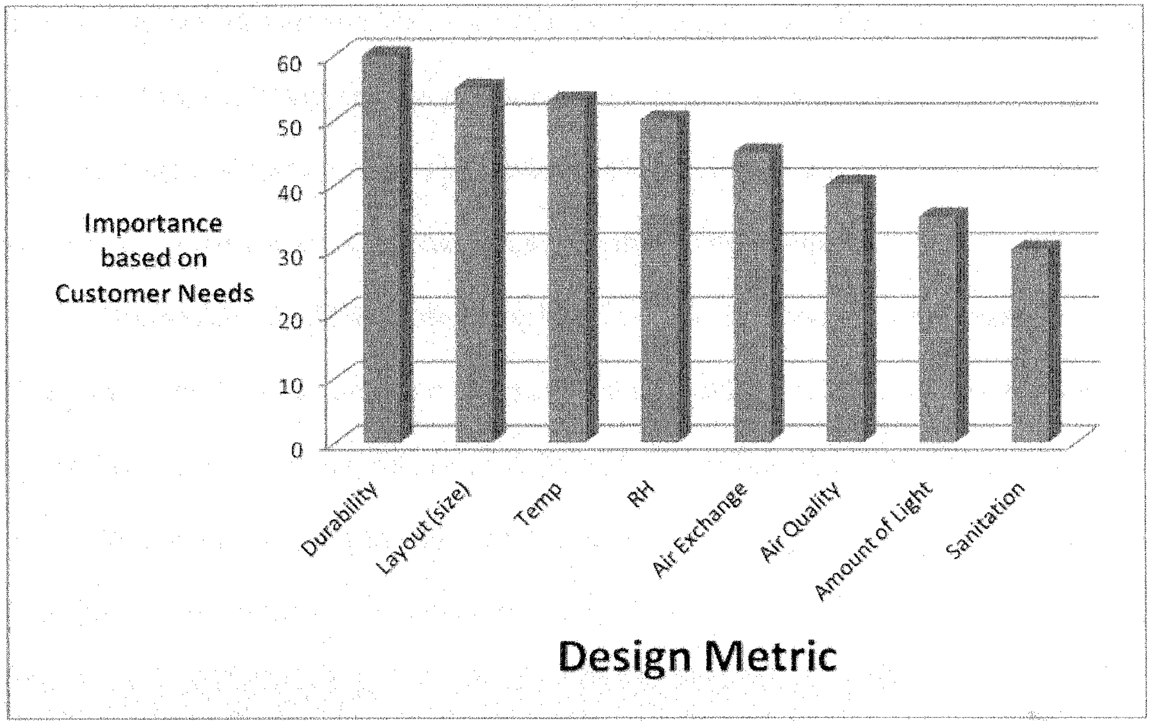

Figure 1. Weighted importance of design metrics based on the ranked list of customer needs.

2) Overview of Borko, Mali

Seed potato farming in the village of Borko, Mali started when Borko was identified as an uncontaminated site. It then became apparent that seed potatoes could be profitable there. Currently, this crop is being imported from various parts of Europe to supply the potato needs of the Sub-Saharan region of Africa. This is not only costly but also unsustainable. The shipments of seed potatoes are often expensive and damaged, incurring great losses for the people of the area.

A solution to this problem was found through the Mali Agribusiness Center, the local college. A test plot of a two varieties of seed potatoes, Sahel and Clauster, were planted near the capital city of Bamako. Approximately 80,000 mini-tubers total were developed at this location and distributed to various parts of the region. 3,000 of the initial 80,000 were sent to the village of Borko for pilot testing. The collaborators, including members from the Mali Agribusiness Center and the writers of the grant hoped that this effort would support a new business venture for many countries in West Africa. Because there is already a seed potato market in this region, the successful development and storage of these potatoes would create a profitable enterprise.

During January 2010, three of the University of St. Thomas Team members (Ryan Chapman, Brett Mernin, and Nick Shannon) traveled to Borko, Mali. Borko is located approximately 400 miles north-east of the capital city of Bamako. The city is situated east of the main road in a lush valley settled between two major mountainous formations. See Figure 2 below for an aerial photograph of the city of Borko.

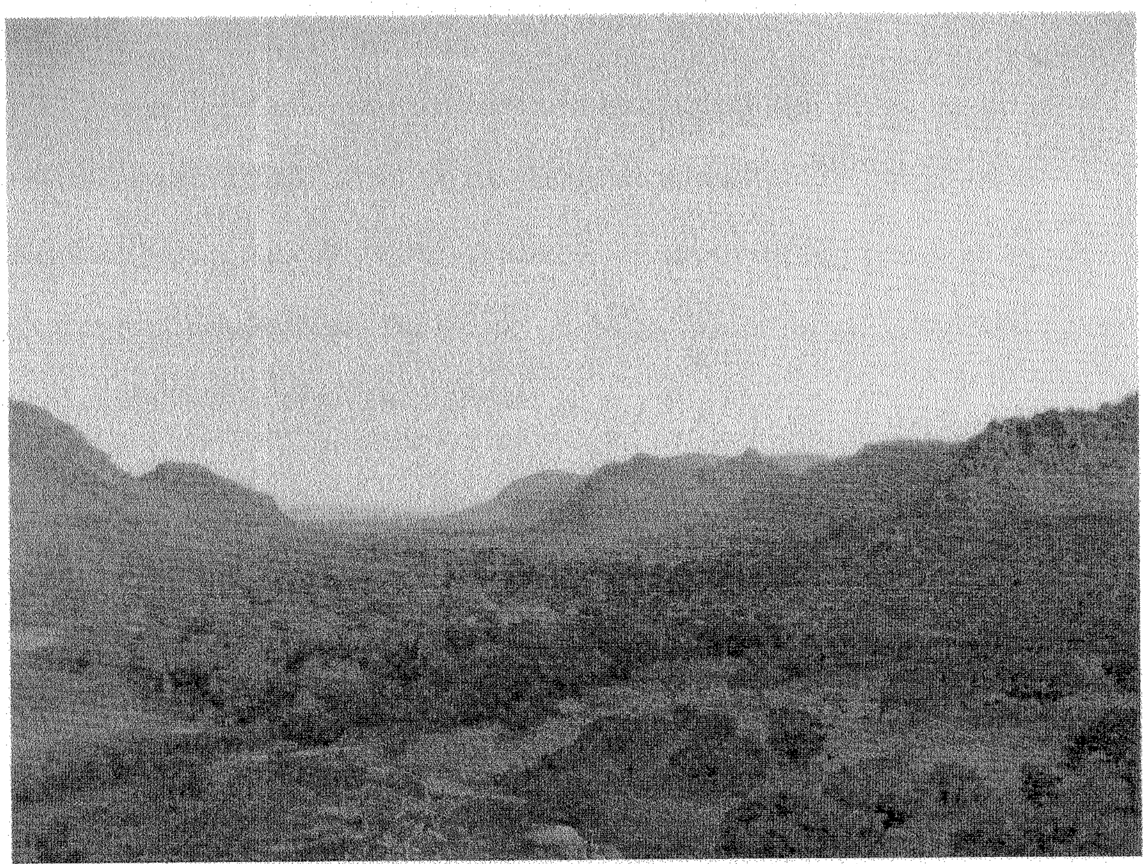

Figure 2. Photograph of the city of Borko, Mali.

Aside from gaining valuable cultural information, interviews were conducted with the locals of Borko while data was collected to assess the feasibility of the project.

a) Local Conditions

Similar to the rest of Mali and Africa in general, Borko experiences three major seasons. The rainy season occurs from June until December. The “cold” season follows with temperatures topping out around 100°F. The “hot” season is the bookend for the wet and cold seasons. Temperatures can reach 120°F during this season. In addition to temperature and humidity readings, solar radiation levels were found in Borko. The sun shines from 7:00AM until 5:00PM everyday. This is approximately ten hours of full strength sunshine. A solar power evaporative cooler became the focus as a result of the dry, hot conditions paired with the amount of available sunshine.

b) Local Agriculture Practices

Current local agriculture practices were assessed through interviews conducted with the farmers of Borko as well as local agriculture experts. Currently, there are several methods of agricultural storage based on whether the crop needs to be hot, dry stored or cold, humid stored. The hot, dry stored goods (onions, garlic, and tobacco) are stored in hand-woven bags in trees (Figure 3).

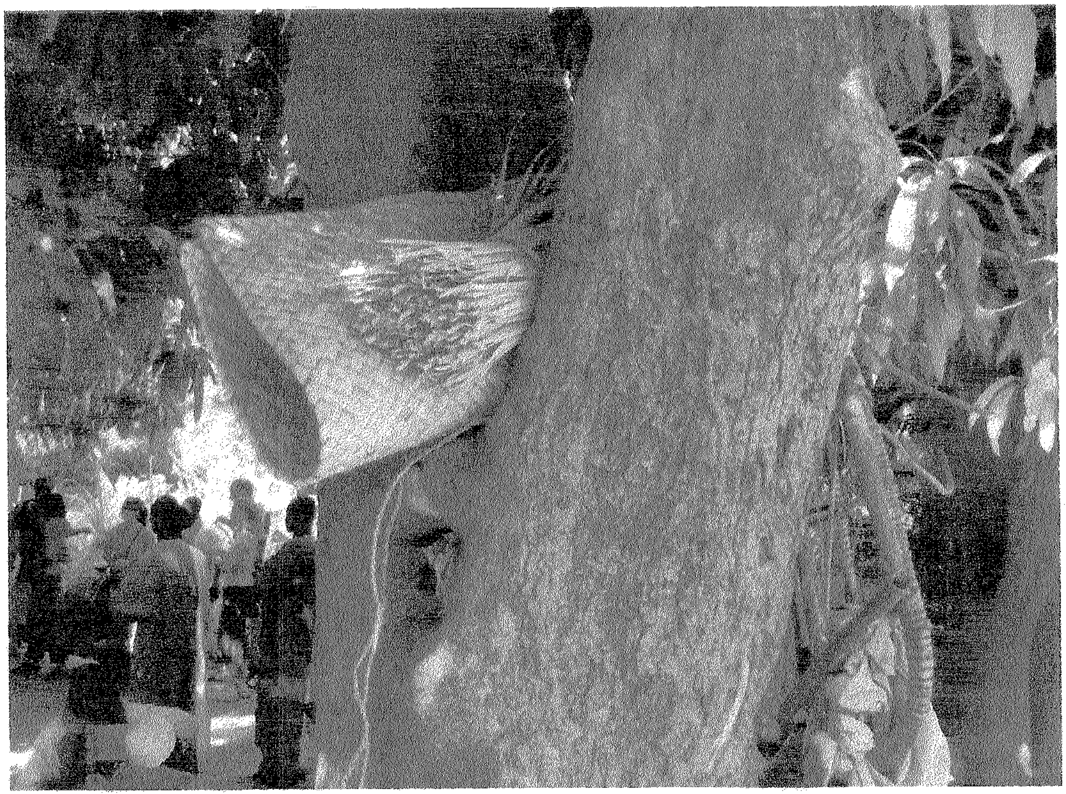

Figure 3. Hot, dry storage method of hand-woven bags in trees.

Ideally, the seed potatoes (a cold, humid stored crop) would be stored in a western style refrigerator with controlled temperature and humidity levels. This is currently available just outside the capital city of Bamako (Figure 4). Unfortunately, this is too far of a drive to ship the potatoes currently in Borko.

Figure 4. Western style refrigerator outside the city of Bamako, Mali.

Since the travel is too far from Borko, the villagers offered the UST team several locations within the village that they thought would be good for cold, humid storage. The first of these were what the locals termed caves (Figure 5).

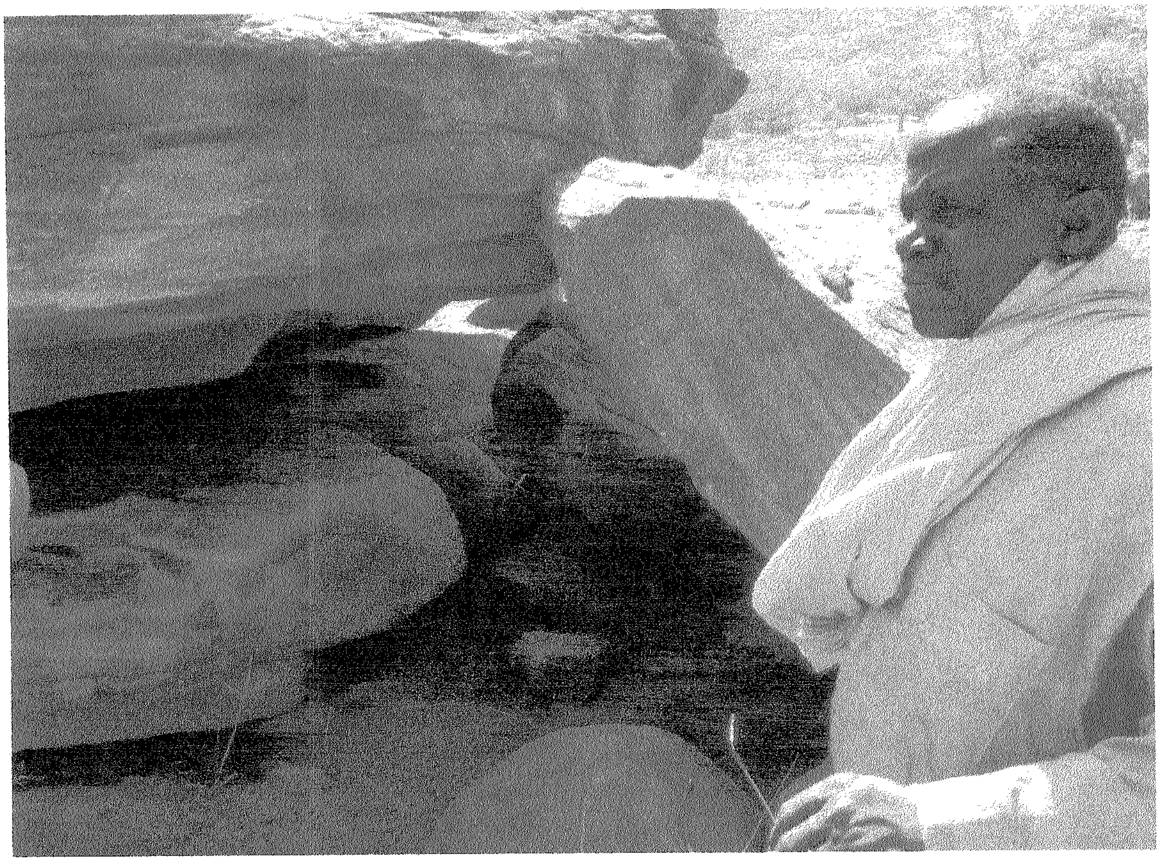

Figure 5. "Caves" for possible seed potato storage.

This location, although cold relative to what the people of Borko experience, is not cold enough to store seed potatoes. A secondary location the locals offered to us was an already built mud-brick building (Figure 6).

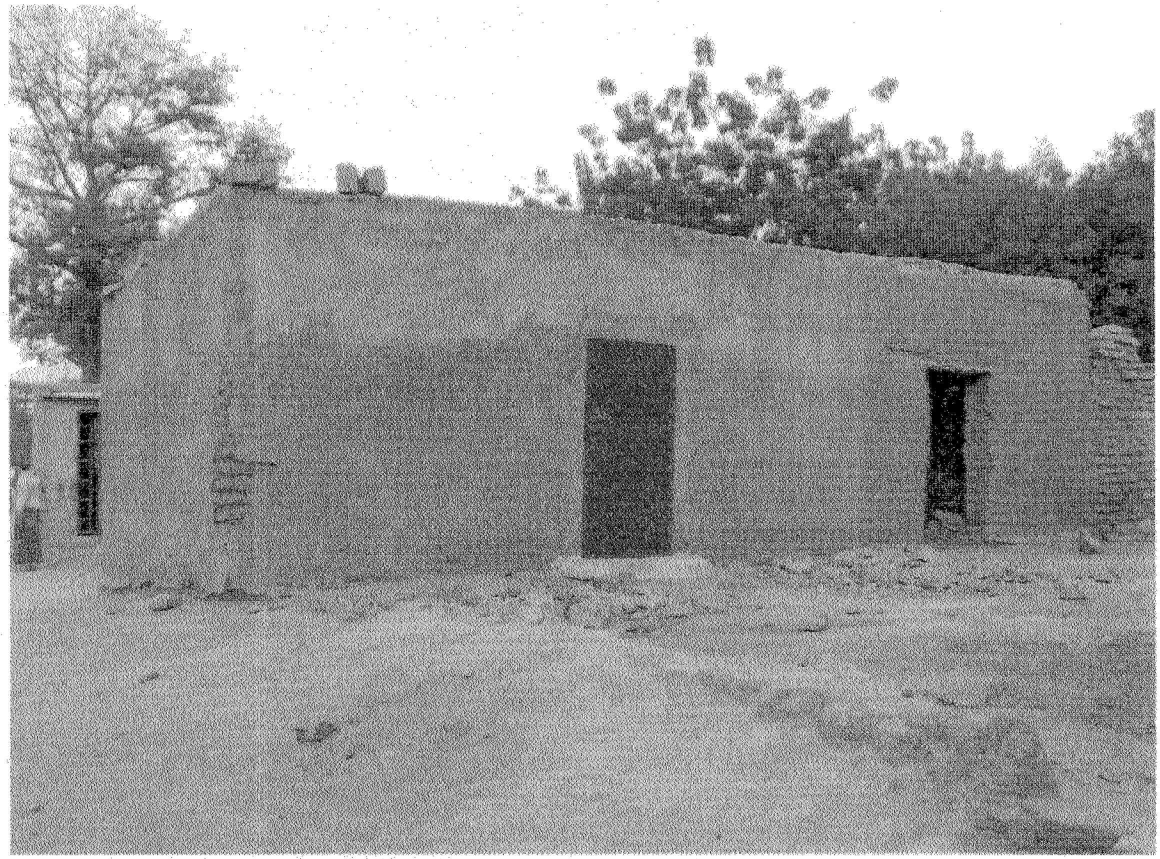

Figure 6. Mud-brick building for possible seed potato storage.

Again, while this building offers cooler temperatures than ambient, it is still not cold enough to store seed potatoes successfully.

3) Engineering Design Challenge

The engineering challenge arose when comparing the storage requirements of a seed potato to the natural conditions of the village of Borko. Storage is a critical factor for the seed potato generational development process. Generational development is necessary for these potatoes to enter into the market. This means that it will take several seasons of harvesting, storing, and replanting the tubers to turn them into usable produce. If the potatoes become diseased, rot, or wilt while they are being stored between seasons, it would have catastrophic consequences on the outcome of the project.

When storing seed potatoes, the determining factor of storage conditions is the dormancy period of the potato between growing seasons. This time period requires specific conditions (temperature, humidity, and air flow) that allow for little fluctuation in the storage environment. Potatoes generally require low temperatures (5-10°C) and high relative humidity levels (90-95%) during storage. These conditions protect against premature sprouting, wilt, and rot.

Although the village of Borko is an ideal location for growing and developing seed potatoes, it also has some of the worst conditions possible for a feasible storage environment. Temperatures in Borko can reach as high as 50°C with relative humidity levels below 10% when it is not the rainy season. To compound the problem, there is no readily available electricity or reliable plumbing in the village. This is necessary to counteract the vast differences between the ambient conditions and the desired conditions for storage.

The challenge then was to be able to successfully store the 3,000 seed potatoes between growing generations for as long as 6 months of the year using a primarily passive cooling system. A passive cooling system is the best option because it requires little technical training or knowledge from the users in the village. Therefore, techniques such as evaporative cooling, water conservation and creative insulation were necessary for a successful storage mechanism.

B) Overview of Current U.S. Seed Potato Storage Practices

Seed potato production across the northern plains and Rockies is a very profitable business in a volatile climate. This requires producers to take the utmost care when storing seed potatoes. Due to abundant energy resources, technologies, and great amounts of available skilled labor, producers are able to store their potatoes in very large buildings with sophisticated HVAC and control systems. These sophisticated systems allow the producers to store potatoes at a prescribed temperature and humidity year round, regardless of the outside environment. These systems normally consist of a large building made with highly insulated metal walls and roofs constructed on a concrete floor slab. They utilize large, industrial sized heating and cooling systems similar to those found in large commercial buildings. They also employ a wide variety of sophisticated humidification systems such as atomizing humidifiers or boiler steam humidifiers.

C) Explanation of Zeer-Pot Evaporative Cooling

Traditional evaporative cooling is often employed by using a basin of water and a fan, but this application will use an African technology in evaporative cooling known as a zeer-pot. A zeer-pot is a simple thermodynamic device that is traditionally used on a smaller, hand held scale to keep produce fresh for hours while it is being sold in the local market using no electricity. A farmer can achieve this sustainable level of cooling by obtaining two fired-clay pots of different sizes. Then, the farmer can place the smaller inside of the larger, and fill the layer between the two pots with wetted sand as shown in Figure 7.

The secret to the success of zeer-pots is to have the structural layers of the pot (in this case fired clay) with high enough levels of porosity. This allows the transfer of evaporated water from both the inside of the inner pot and the outside of the outer pot into the surrounding environment. This level of porosity can be achieved simply by adding sawdust or another combustible element to the clay mixture that will be eliminated through firing. These materials leave space behind to allow the evaporated water to travel through. Since this technology does not specifically need electricity and has already been successful in produce storage, it is a promising solution for the problem of storing seed potatoes.

Figure 7. Traditional zeer-pot.

In the summer of 2009, University of St. Thomas student Hans Drabek began the construction and research of various sized zeer-pots using an assortment of bricks and sand. The zeer-pots that Hans created occupied approximately one cubic meter, and were built using different kinds of fired ceremics such as bricks and other structural materials. At first, Hans built a zeer-pot that used no porous structural elements. This resulted in very minimal cooling and almost no evaporative cooling. Next, he attempted a zeer-pot using fired, porous bricks held together with an adhesive agent in order to assure structural integrity. Again, this technique resulted in low efficiencies and minimal evaporation. By removing the adhesive and allowing space for evaporation between the bricks, evaporation and cooling effects were greatly increased.

Another increase in the efficiency of the evaporative cooling capabilities of the zeer-pot was seen when Hans sealed the top of the structure with a wet piece of fabric. This increased the surface area for evaporative cooling as well as creating a much better contained environment.

D) Overview of Improved Zeer-Pot Design

The specific zeer-pot evaporative cooling design for the village in Borko will attempt to maximize the surface area for evaporation, as well as structural integrity. These were two aspects of the zeer-pot that were not necessarily obtained by Hans Drabek's brick model. As outlined, the design of a zeer-pot requires two porous transmission layers for the water to evaporate through. Additionally, two walls with great structural integrity are necessary against the pressure of the sand.

After several design iterations, traveling to the village, and exploring the local markets, an entirely steel zeer-pot design was selected to store the required amount of potatoes. The structural integrity of the design will be obtained by using steel columns and welded joints in a repeated pattern around the perimeter of the container. The sand containment will be accomplished by using a low gauge steel mesh design to operate on a removable pin-and-hinge system. This will allow for easier construction and give the users the opportunity to quickly replace the sand layer if necessary. The porous layer is achieved by using a layer of thin, porous, water-passing geotextile in conjunction with the steel mesh. This will hold the sand in the walls and allow evaporation to occur. Within the container, the potatoes will be stored in nylon mesh bags on a metal rack system. The potato farmers will be able operate this system by using a long pole with a hook placed on the end. The final design was selected mainly to have a greater evaporative cooling effect than the zeer-pot modeled by Hans Drabek. This was accomplished through maximizing the surface area available for evaporation. In addition, this design has a more reliable form of structural integrity in comparison to non-cemented bricks. This was critical for the size of this specific application.

Part II – Body

A) Framing the Design Challenge

Because there were a seemingly infinite number of ways to attack this engineering challenge, selecting the best way was difficult. The only way that seemed appropriate was to divide up major portions of the problem amongst the design team. These separate sections included cooling method, power generation, structural integrity, and controls. Once each section was divvied up and the design requirements were paired with those sections, a technical and economic model seemed to be the next logical step. This model was the best way to discover what technical metrics (cooling capacity, power consumption, cost, etc.) could be attained given a number of varying inputs.

After the technical and economic model was finalized, three members of the engineering design team traveled to Borko. The major purposes of the trip were to discover what the villagers desired, take meteorological data, build a temporary zeer-pot, collect data on that structure, and revise the customer's design requirements.

Upon returning from Borko, all five members of the team were charged with brainstorming all possible solutions for their own specific section of the problem. This was done through the use of mind maps (also known as web diagrams) as well as concept classification tables. Combining the information gained in Mali with the possible solutions generated during brainstorming sessions allowed the team to narrow down the solutions from all possibilities to the best solution available.

Once the final design concept was selected, specific theoretical principles needed to be researched. This included basic evaporative cooling concepts as well as structural demands that the steel zeer-pot might experience. From this information, a finalized design was selected. To evaluate the effectiveness of the final design, tests were conducted to discover the specifics of the mass transfer, the efficiency of the selected technology, and the structural integrity of various proposed materials. Finally, this data was used to polish off the completed and finalized design.

B) The Use of a Technical Model

Technical and economic models are used in industry to identify critical design decisions in a system. The critical design decisions are the decisions that have the greatest impact on price and performance. Technical models are used to model system design decisions via sets of predictive formula. The model contained a collection of calculations with variable inputs (design decisions) whose output predicted the resources required and performance of the system with the chosen design decisions. The economic model used the output of the technical model as an input to predict the price of a system. When the design decisions were changed the effect on the entire system including cost was immediately calculated. With a predictive technical model of a system, the effect of changing a design decision on resulting resource cost and performance was immediately determined.

The developed Excel technical model helped to efficiently meet design requirements. It calculates the exact resources needed making it easier to budget time and money. This technical model was designed to be able to create a theoretical potato storage system of any size in any place. To allow for a different location, the NASA data at the end of the model would need to be replaced with corresponding data for the new location. If a different size of structure is required, the amount of potatoes to be stored must be modified. In short, the technical model that was created can be used for any seed potato application at any location in the world.

The data gathered from NASA was at times helpful but other times hindering. On one hand, NASA had surface temperature and solar radiation data dating back nearly twenty years.