Document 523
ALTERNATIVES ANALYSIS REPORT

CHAPTER: EWB-JSC South Houston Professionals
COUNTRY: Rwanda
COMMUNITY: Mugonero
PROJECT: Fruit Dehydration for Rwanda Orphanage
TRAVEL DATES: 07/2011

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Alternatives Analysis Report Part 1 – Administrative Information

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2. Travel History

Dates of Travel	Assessment or Implementation	Description of Trip
May 2005	Assessment	Mugonero Hospital (water quality/quantity)
January 2006	Implementation/ Assessment	Mugonero Hospital (solar lighting installation and water collection assessment)
June 2006	Implementation/ Assessment	Mugonero Hospital (rainwater catchment installation) Mugonero Orphanage (water quality/quantity assessment)
August 2007	Implementation	Mugonero Orphanage (water treatment installation)
August 2008	Assessment	Mugonero Orphanage (fruit drying)

3. Project Discipline(s):

Check the specific project discipline(s) addressed in this report. Check all that apply.

Water Supply
____ Source Development
____ Water Storage
____ Water Distribution
____ Water Treatment
____ Water Pump

Sanitation
____ Latrine
____ Gray Water System
____ Black Water System

Structures
____ Bridge
____ Building

Civil Works
____ Roads
____ Drainage
____ Dams

Energy
___ Fuel
___ Electricity

Agriculture
____ Irrigation Pump
____ Irrigation Line
____ Water Storage
____ Soil Improvement
____ Fish Farm
____Crop Processing
_X_ Equipment

Information Systems
____ Computer Service

4. Project Location

Longitude: E 29 º 17.264’

Latitude: S 02 º 10.032’

Alternatives Analysis Report Part 2 – Technical Information

1. INTRODUCTION

The Johnson Space Center (JSC)/South Houston Professional chapter of Engineers Without Borders-USA has been working in Rwanda since 2005 on water treatment, water provisioning, and energy provisioning appropriate technologies in the Mugonero region. After installing a water treatment system at the L'Esperance children's orphanage in the summer of 2007, the team has focused its efforts to help the orphanage reach economic sustainability through the processing and sale of dried fruit. An initial fruit drying assessment trip in 2008 provided additional information and important lessons learned, which have lead different prototypes being investigated by EWB-JSC chapter members. As part of our implementation trip planned for July 2011, we plan to install and test a solar fruit dehydration prototype, which the orphanage director will ultimately assess for feasibility and appropriateness for full scale operation at the orphanage.

2. PROGRAM BACKGROUND

The EWB-JSC chapter has for several years worked to engineer infrastructure solutions at the L'Esperance Children's Village Kigarama orphanage in rural Rwanda near both the town of Kibuye and the famed Mugonero Hospital. The orphanage is home to 127 orphans, many of whom have the HIV virus, resonating back to the Rwandan Genocide in 1994. The orphanage is supported in various ways by EWB-JSC, an EWB Colorado chapter, Manna Energy Limited, Birambye International (a non-profit engineering firm in Colorado), and several other non-profit Non Governmental organizations. EWB-JSC has been responsible for providing a successful Bring-Your-Own Water (BYOW) purification and filtration system to the orphanage and has collaborated in varying levels of effort with EWB Colorado on several other projects, including rainwater catchment, solar power, high efficiency cook stoves, and crop irrigation.

The orphanage comes under managerial and financial control of the Seventh Day Adventist Church, and its on-site director is Mr. Victor Monroy, a horticulturist originally from Guatemala. In 2007 Mr. Monroy asked EWB-JSC to assist in developing infrastructure for a vast agricultural project he was initiating, that would allow the orphanage to become economically self-sufficient by selling highest quality premium produce in the developed world. Drip irrigation, water storage, food processing, sterile facilities, water management, waste management, packaging, food storage pre- and post-processing, and improved energy infrastructure are all necessary features of this endeavor. Fruit drying is on the critical path to success of this project because (1) the orphanage lacks sufficient electricity to refrigerate the fresh produce, (2) transportation to the markets is not possible on a schedule to keep fruit from spoiling, and (3) roads follow 26 kilometers of exceptionally tortuous dirt paths that would bruise whole produce.

3. DESCRIPTION OF COMPARISON METHODOLOGY

Two different fruit drying solutions were investigated simultaneously for implementation and evaluation in Rwanda in July 2011. The intent of this approach was to permit the orphanage director to use both options in the field and provide EWB-JSC with feedback and a recommendation on the best option (or combination of options) to scale up for drying all the fruit that will be produced. The first of these solutions was a continued pursuit of a solar dryer, implementing lessons learned from the prototype installed during the 2008 trip. The second was a kitchen waste heat dryer. However, concerns regarding practicality and safety after internal evaluations eliminated the kitchen dryer, leaving the solar dryer technology as the only technology to be taken to the field. The team is now focusing all efforts on the current solar dryer technology and opportunities to adjust the design to meet cultural & geographical demands & constraints once the orphanage director has had time to evaluate the technology in country.

4. DESCRIPTION OF ALTERNATIVES

4.1. Solar Drying

Solar drying offers several advantages as compared to simple sun drying. First, the air temperatures generated in a solar dryer can produce dried products with low final moisture contents. This reduces the risk of spoilage during processing and in subsequent storage. Also, the high air temperatures provide a deterrent to insect and microbial infestation. As solar dryers function by encasing the food product, the enclosed structure affords additional protection against dust, insects and animals. The resulting dried food products can then be safely stored for long periods, have good nutritional qualities and have cash value for producers.

Recognizing the need for improvement over current solar dryer designs, over the past two years, EWB-JSC has been developing a number of solar dryer prototypes in a continuing effort to provide the Mugonero Orphanage with a reliable and sustainable means of drying fruit. The finalized prototype to be constructed during this implementation trip is a box design that uses direct and radiative solar heating and natural convection as the primary means of heating the dryer box and drawing air through it. The steps taken to reach the final solar dryer design is described in Section 7.1 of this document.

The solar dryer prototype has been designed to maximize use of materials that are able to be sourced in country. This is a design feature to allow the dryers to be readily reproduced as needed without future trips on the part of EWB-JSC. The availability of most materials has been verified either by EWB-JSC members on previous trips, or through contacts the group has in Rwanda. Materials that have not been determined to be available in country will either be found during the implementation trip or suitable substitutes made.

There are three main components of the solar dryer: the dryer box, the insulated bottom layer, and the outlet chimneys. The dryer box is made of three sides of the dryer box that are wood, with the fourth side remaining open with a screen to restrict bug access to the fruit and serving as the fresh air inlet. Fruit will be placed on two layers of trays inside the dryer box. The drying trays are supported by wooden slats attached to the sides of the box. The bottom of the box is made of corrugated metal either painted black or blackened with charcoal for increased solar heating. The top of the box is made of UV stable Plexiglas attached to a wooden frame using sheet metal screws. The dimensions of the box as built in the US are 4'x 6'x 8". The box to be built in Rwanda will adhere approximately to these dimensions, with considerations given for dimensional variations due to being in a country that uses the metric system.

The bottom of the dryer is an insulated layer that is a 2"x2"x2" frame attached to the bottom of the main dryer box with corrugated insulation and a final bottom layer of sheet metal that is attached to the 2"x2"x2" frame to insulate the main dryer box. This creates an insulating layer on the bottom of the dryer box and reduces radiative heat losses emitted from the bottom of the dryer box.

The chimneys are made of galvanized furnace ducting and the dryer as built and tested in Houston has two 4" diameter chimneys. The prototype to be built in Rwanda will use either 4" ducting in 2 chimneys, or a single 6" duct. Painted black, the chimneys are roughly 3' tall and function as a black body that as it heats up, creates a low pressure zone, drawing air through the dryer box and out through the top of the chimney. See **Error! Reference source not found.**.1-3 for overall images of the solar dryer.

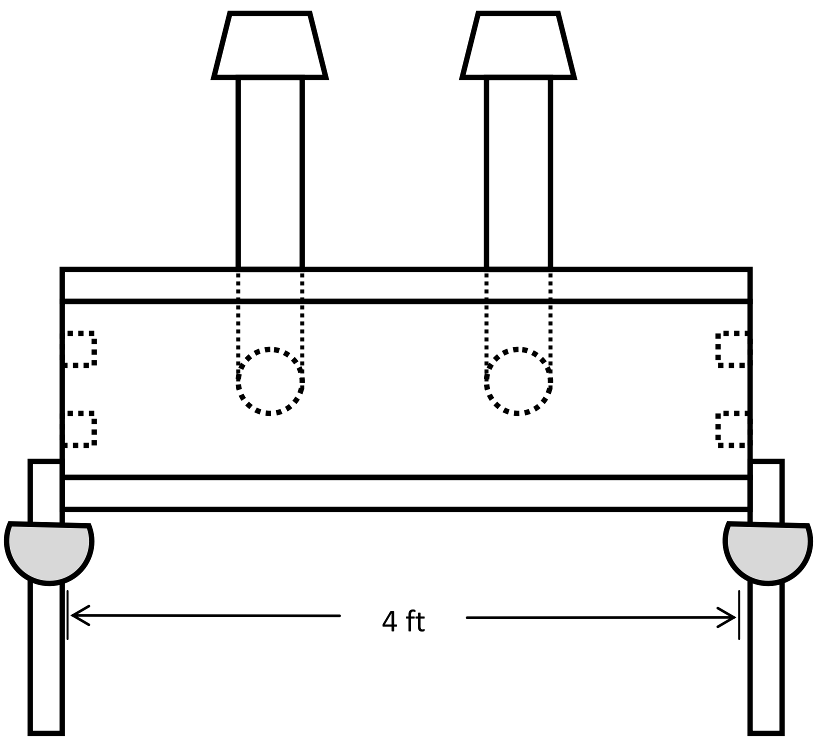

Figure 4.1-1 Front View Schematic of Solar Dryer

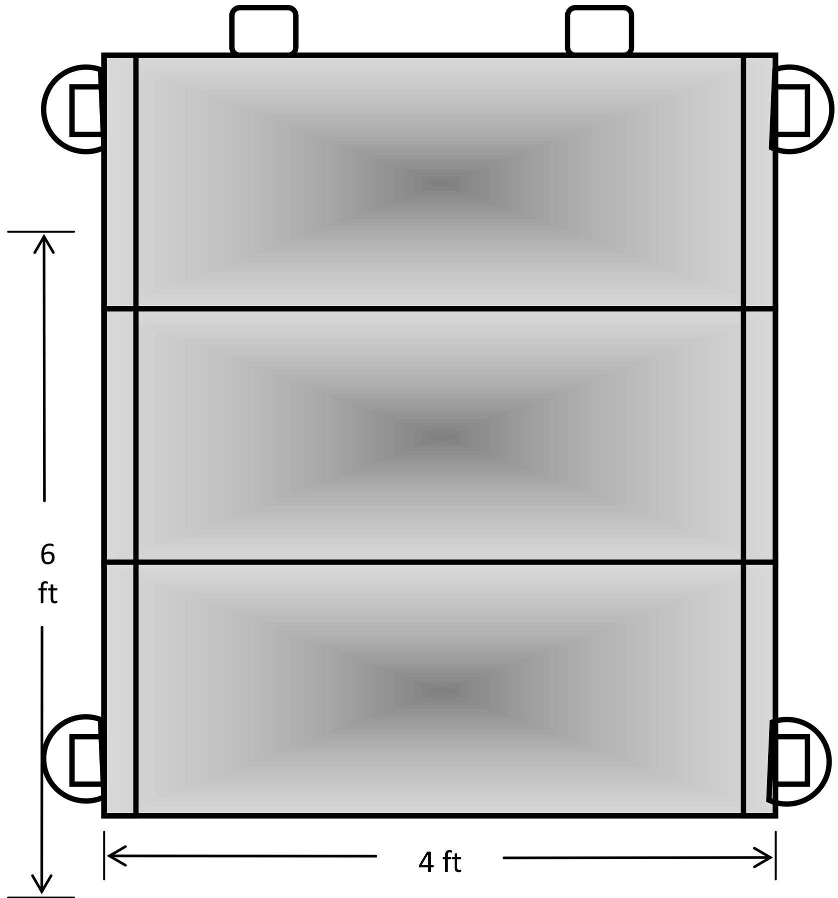

Figure 4.1-2 Top View Schematic of Solar Dryer

Figure 4.1-3 Completed Solar Dryer

The dryer box will be lifted off the ground by four legs made of PVC pipe. Each hollow PVC leg will be placed over stakes driven into the ground. The PVC pipe will have holes drilled in it to accommodate the insertion of a pin that, when the leg is placed over the stakes, rest on top of the stake. This will allow for adjustment of the height of one end of the dryer box, thus changing the angle of the solar dryer as seasons change to account for different angles of the sun and optimize heating of the dryer box.

The PVC legs will have plastic bowls clacked to the legs of the dryer. These bowls will have a hole drilled through the bottom for the PVC to pass through. The bowls will be sealed to the leg with caulking to make them water tight. The bowls will then have water poured into them to serve as a barrier against crawling insects. In addition, both the inlet of the dryer box and the outlet of the chimneys will be covered with screen to guard against flying insects.

4.2. Kitchen Waste Heat Drying

Understanding that solar drying is limited to sun availability and weather conditions, the second dehydration option that the chapter investigated involves utilizing waste heat from the kitchen stoves used in daily cooking operations to dry the fruit. This solution in the late design phase and is being constructed at a field site that is scaled and setup to mimic the setting in Africa.

This dryer transfers the residual heat from flue gasses and steam in the orphanage kitchens to fresh air, allowing warm-air drying of wet fruit at controlled, optimized temperature and flow rate. The prototype will be integrated into an existing Nez roof-style kitchen with airflow supplemented by solar powered fans.

The general flow of thermal energy in the Kitchen dryer can be characterized as “from Flue to Fresh air to Fruit”. There is in addition a large thermal reservoir to regulate the temperature and to store excess heat for later use, much like a capacitor in an electric circuit. This buffer consists of numerous sealed aluminum catering trays partially filled with paraffin wax, whose latent heat of fusion is enormous, stored and released in the optimum temperature range for fruit drying. The reservoir system stores heat in both the fresh air and flue gas flows and delivers it to the fresh air flow.

Because the orphanage rocket stoves are already highly optimized, it is a challenge to extract the majority of the heat from the effluent. This result in an intricately-balanced design of many factors, including flow rates, temperatures, wax melt temperature, wax quantity, and fruit loading. The thermal losses go down and heat transfer efficiencies go up as the scale increases, and thus the scales of a workable heat exchanger, thermal reservoir, and fruit drying area are all necessarily large. EWB-JSC intended the dryer to handle approximately 40kg of wet fruit per day, delivering at least 90 Megajoules to the fresh air around the fruit out of the nearly 250 Megajoules used each day in cooking. (36% thermal transfer efficiency from the waste heat to the fruit).

Slanted parallel-duct rectangular heat exchangers take much of the heat out of the escaping combustion gasses and steam from the cook stoves and deposit it into fan-blown fresh air that is ducted to the fruit. The temperature of the fresh air is optimized to melt the maximum quantity of wax during the six-hour cooking time.

After the combustion products leave the heat exchangers, these flue gasses are still very hot, so it is essential to preserve the excess heat for later use. Paraffin wax is used to buffer and to store the heat, with a melting point centered within the acceptable fruit-drying temperature range. Although a limited number of wax trays interface directly from the flue gasses, the bulk of the wax trays interface directly with the fresh air supply directly after the flue gas heat exchanger. This interchange between the hot fresh air and the wax not only stores heat into the wax, but regulates the air temperature to the wax freeze point, no matter what the fresh air temperature is after the flue gas heat exchanger. After heat exchange with the fresh air and a passage over a wax thermal reservoir, the flue gasses travel under the elevated fruit drying box to directly heat the air volume within it.

Additionally, in the transitional cone over the stove that feeds the flue gasses into the slanted heat exchanger, the flue gasses flow under a canister of Calcium Chloride or Silica Gel (TBR) desiccant, (one canister per stove) and the high temperature (200C) recharges the desiccant for use during the final stage of the fruit drying and during temporary storage.

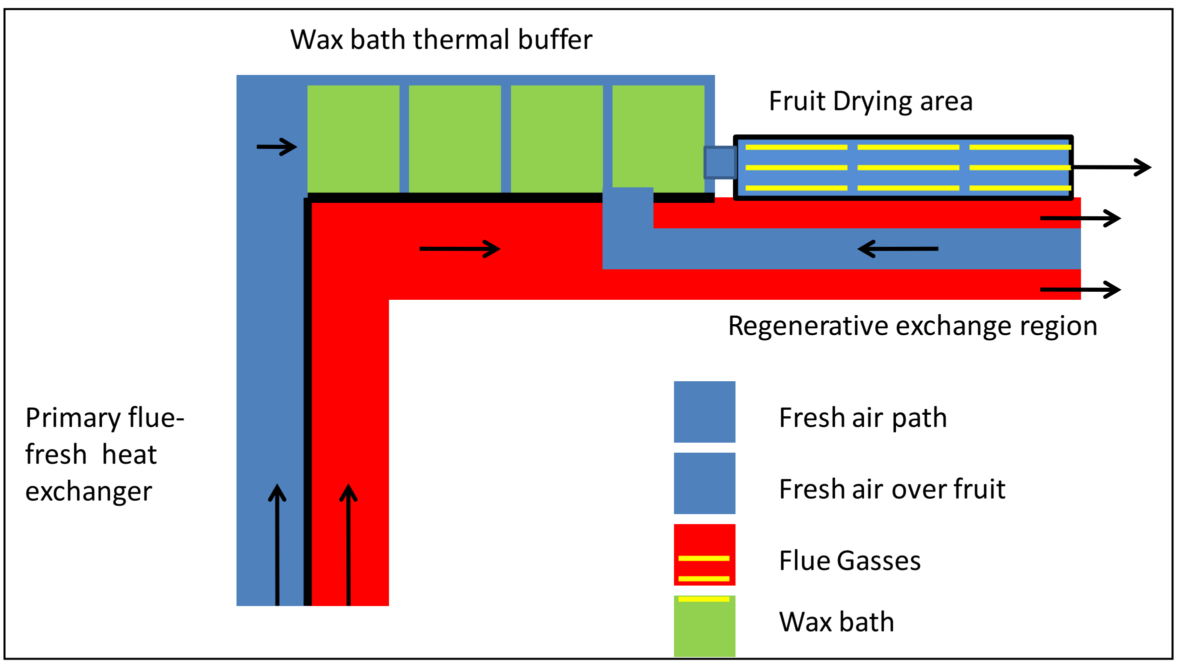

Figure 4.2-1 Overview of kitchen dryer airflow

Due to the complexity of this design, additional tests were performed to confirm structural integrity and safety. The tests included tensile and compressive strength tests-to-failure of the bamboo joining technique, structural loads analysis testing of the major load-bearing structuresThe team has conducted touch temperature tests of the recommended insulation material under working conditions, and flammability tests on boric-acid-treated indigenous insulating materials. The team has reviewed and accepted the MSDS data sheets on all proposed seals and materials in the design. A formal safety review with hazards and controls has been held on all facets of the design.

While the Kitchen system offers the advantage of year round drying, the EWB-JSC design review yielded significant safety and structural concerns that could not be resolved by the summer 2011 and may not be feasible given the size and resources of the chapter long term. For this reason, the design was deemed inappropriate for the summer 2011 implementation.

5. ANALYSIS OF ALTERNATIVES

5.1. Solar Dryer Testing Results

Testing of the solar dryer has shown that it is capable of drying pineapple on both sunny and cloudy days, with the main variable that is impacted by the weather being the time until the fruit is fully dry. A function of the design of the solar dryer was that it is loaded to varying levels based upon the weather. Since the fruit itself greatly adds to the thermal mass of the dryer, and as evaporation of water occurs from the fruit heat energy is removed from the air inside the box, the fruit itself serves as a temperature buffer. By virtue of this the dryer is loaded fully on sunny days, but only partially loaded on cloudy days to ensure that the optimum temperature range of 125-135 ˚F for fruit drying is achieved. On days where the dryers are partially loaded, more dryers will be required to dry the same quantity of fruit. However, on very cloudy or rainy days, the solar dryer was unable to achieve the optimum temperatures, even while empty. This restricts the periods of the year where the solar dryer would be able to reliably dryer fruit to a commercially viable product level. Temperature results from a typical test are shown in Figure 5.1-1.

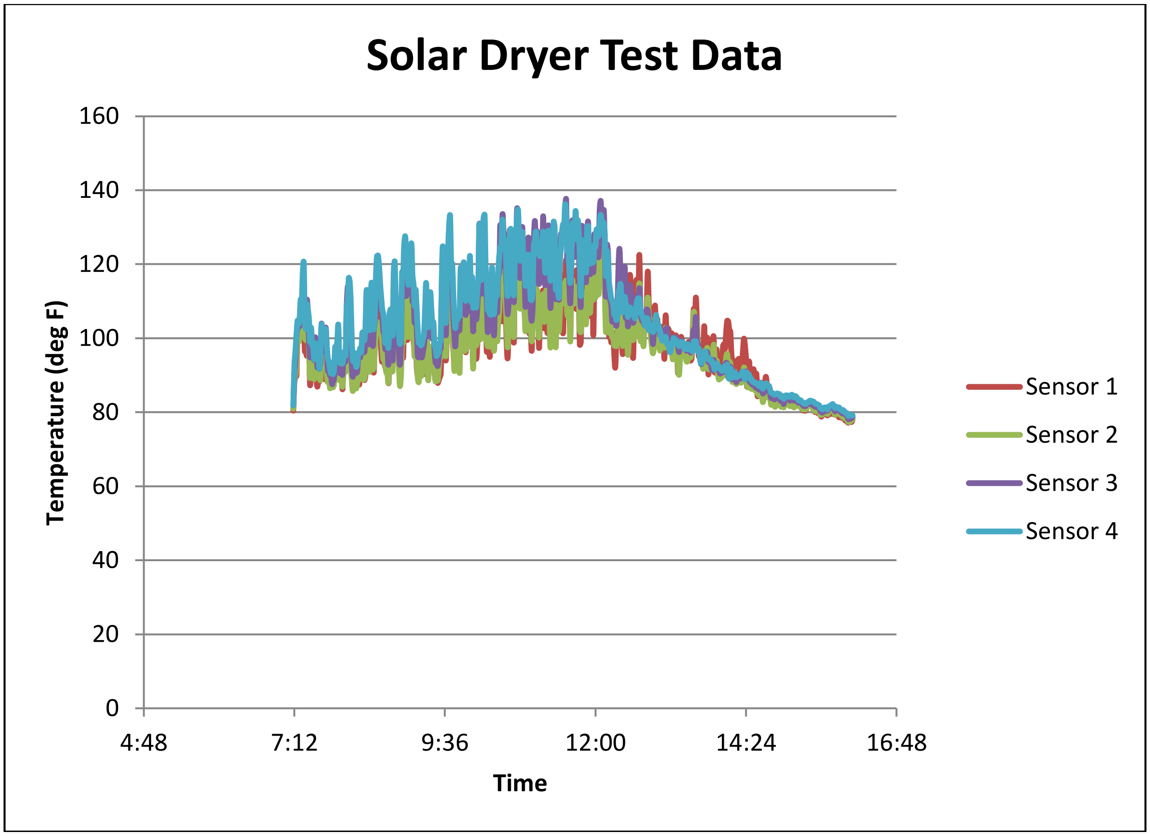

Figure 5.1-1 Solar Dryer Temperature Data

5.2. Kitchen Dryer Testing Results

Preliminary testing of the kitchen dryer indicated that it was capable of drying fruit. However, as previously mentioned, work on the kitchen dryer was terminated due to structural and safety concerns prior to actual completion of a full test structure. As a result, all comparative points in this study are based upon design parameters of the kitchen dryer or testing data obtained during prototyping.

5.3. Operational Costs

From a comparative perspective, the actual operational costs of both dryers came out relatively similar. This is due to the fact that, aside from labor of loading the dryers, the source of their heat energy is either the sun, or kitchen waste heat. As the kitchen fires would be burning regardless of whether the kitchen dryer was implemented or not, this is not viewed as an additional cost incurred by the orphanage.

5.4. Maintenance

Due to the complexity of the design and the hot, moist environment of the kitchen, it is expected that maintenance of the kitchen dryer would be higher than that of the solar dryer. Based upon the experience with the test articles built in Houston, this expectation was validated.

5.5. Safety

Considering that the proposed systems are to be installed at a functioning orphanage, the safety of the designs is an overriding concern to EWB-JSC. Safety concerns for the solar dryer consist largely of touch temperatures while operating, since all sharp edges will be covered. Ergonomic issues for the solar dryer were taken into account with the design, and handles will be attached to the dryer and lid to provide for ease and safety of use.

The kitchen dryer, by virtue of being suspended above an active work space and having a considerable volume of melted wax within it, posed a significant safety risk, both in terms of the structures suspension over the kitchen area and a flame risk from wax off gassing. By virtue of these factors, the safety concerns for the kitchen dryer are a primary reason why EWB-JSC is not moving forward with the implementation of a kitchen waste heat dryer at present

5.6. Complexity

The solar dryer is relatively straight forward and not complex. The only complexity to its operation is the variation in loading which takes place due to weather variations. These variations in loading will be taken care of through instruction of the orphanage staff. In addition, the duration of the trip has intentionally been chosen to allow for construction of the dryers to be built on this trip to be quickly completed, with days remaining for the team to fully transfer knowledge of dryer operations and loading based upon weather variability.

The kitchen dryer as tested is a very complex design, involving multiple ducts, cross flow heat exchangers, wax pots, fans and dryer boxes. During the day, smoke inlet ducts are required to swing out of the way so that pots can be stirred and removed. By virtue of these factors, the complexity of the design for the kitchen dryer is an additional reason why EWB-JSC is not moving forward with the implementation of a kitchen waste heat dryer at this time.

5.7. Sustainability and Appropriateness

Both the kitchen and the solar dryer fit the requirements of a sustainable product. They both use local materials and obtain their energy in a sustainable fashion.

5.8. Effectiveness

Overall effectiveness of the dryer takes into account its ability to provide the orphanage with a means to dry the fruit they produce. To that end, both dryers are effective. However, taking into account the location of the orphanage in a tropical area that has a sustained rainy season, the overall effectiveness of the solar dryer as a year round solution falls short in comparison to the year round capabilities of the kitchen dryer. Part of the reason this pilot trip is being undertaken is to locally assess the year long effectiveness of the solar dryer.

5.9. Impact on Orphanage Operations

Implementation of any fruit drying system will have an impact on operations at the orphanage, by changing the labor required for processing the fruit as well as loading and unloading the dryers. The fruit grown at the orphanage is currently being processed for consumption; additional fruit will be processed for loading into the dryers thus adding to the workload.

The kitchen dryer would have a large impact on the operations of the orphanage kitchens. The cooks would have to pivot segments of ducting out of the way in order to stir pots, or remove pots from the stoves for serving or cleaning. Loading of the trays for the kitchen dryer would require the raising and lowering of the dryer boxes into the kitchen area, impacting kitchen operations during loading.

The solar dryers impact on the operations of the orphanage are that it will take a significant amount of land area to allow for full dehydration of the fruit. The EWB-JSC team has already worked with the orphanage to determine a potential area for the solar dryers, and will asses this location fully during the trip.

5.10. Prototype Comparison

A summary of the costs, materials, constraints, and advantages of the two prototypes can be viewed in the Table 5.10-1.

Table 5.10-1

Dryer Type	Advantages	Limitations	Costs	Materials
Solar	Easy to assemble Affordable Accepted African fruit dehydration methodology Can be easily scaled	Requires additional space requirements May not operate year around due to rain	$322.00	Wood Corrugated Steel PVC, Plexiglas *All materials obtained in country
Kitchen Waste Heat	Can be used year round Complements current behaviors and resources	Labor Intensive Low Fidelity	$1111.50	Stainless Steel Galvanized Steel Fasteners Wax Requires Imported

				and Local materials

5.11. Comparative Analysis

The performance of the two dryers based upon the evaluation points covered in Section 5 is summarized in Table 5.11-1.

Table 5.11-1

	Solar	**Kitchen**
Operational Costs	x	x
Maintenance	x	
Safety	x	
Complexity	x	
Sustainability and Appropriateness	x	x
Effectiveness	x	x
Impact on Orphanage Operations	x	
Selected Dryer	**x**	

Based upon the criteria selected for evaluation, it was decided by the EWB-JSC team to move forward with the solar dryer as a pilot project initially, with the ultimate goal being a full implementation of either the current solar dryer or an updated design, or another dryer type capable of sustainable drying year round on a future implementation trip.

6. DESCRIPTION OF PREFERRED ALTERNATIVE

Rigorous testing using the chapter’s extensive knowledge in prototype testing and projections has yielded strong confidence levels in the viability and acceptability of the solar fruit dryer prototype due to significant advantages and low cost over other alternatives. EWB-JSC recognizes that the commitment to provide a durable, affordable, and user friendly fruit dehydration technology to Rwanda requires a thorough understanding of the technical design as well as the science of fruit dehydration and consumer preferences.

The solar dryer that will be installed by EWB-JSC as part of the pilot project is intended to meet two requirements of the orphanage. These requirements are, in the short term, to be able to dry fruit in small quantities in order to provide potential buyers of the orphanage’s products with samples of sustainably and economically dried fruit. The second requirement is to move forward on testing and training at the orphanage itself of a long term solution to the drying needs. Operation of the prototype will also provide extremely valuable test data in the relevant environment.

7. MENTOR ASSESSMENT

7.1. Tyler-Blair Sheppard, Technical Lead

The current solar dryer design evolved over a series of testing periods and design reviews. The initial dryer design was of a simple gauze tent design. A simple tower of wood was constructed to support several horizontal racks, with mosquito netting being used to support the fruit. Thin plastic sheeting was draped over the wood frame of the tower to provide a greenhouse-like environment inside the dryer tower. Based on testing of this very simple and prevalent design, it was determined that if large scale drying of succulent fruits was to occur, several improvements would be needed, namely increased temperature and airflow over the fruit.

Next, EWB-JSC built and tested another dryer of the solar collector and vertical fruit stack variety. Incoming air was warmed via direct and infrared solar radiative heating, and ducted into a vertical brick tower containing trays upon which prepared fruit was stacked. Brick was selected due to its durability and availability, and this initial design was constructed at the orphanage as test article during the EWB-JSC assessment trip in 2008. However, as testing on the initial prototype continued, it was determined that the design was not capable of achieving the temperatures required for fruit drying, and that airflow through the dryer was still an issue.

After the 2008 assessment trip, a design review of available solar dryer designs occurred and Tyler-Blair began to lead their development. A number of candidates where investigated and it was decided that a simple box dryer would provide the best combination of reproducibility and simplicity, while achieving the greatest flow and temperature levels. It was also decided that testing of the box dryers should proceed with variations to the design being conducted in parallel. To that end, two dryers were constructed, identical with the exception of a single parameter, which would change as improvements to the design were arrived at. Recognizing that two aspects of the design, temperature and flow, required optimization it was decided to attempt to achieve temperatures in excess of those required for drying, and then increase air flow as a means of decreasing temperatures.

The first box dryer prototypes that were assessed consisted of a pair of 6’x2’ box made of 2x4’s, with the bottom made of uncoated corrugated metal. A hinged lid was attached to the top to accommodate loading of the dryer. Attempting to ensure that high enough temperatures were achieved to permit drying, all joints in the boxes were sealed with caulking. The boxes were oriented at a 12 deg angle with respect to the ground to induce flow through it via buoyancy, and were supported by wooden legs. Air entered the lower end of the dryers through a series of 1” holes drilled in the end of the box, and exited the upper end through another series of 1” holes.

Testing of the dryers entailed lids topped with plastic sheeting, corrugated metal, and both regular and UV stabilized Plexiglas. A variety of screen material was tested, as well as unpainted and painted metal bottoms. To improve airflow through the dryer, chimneys were added to the downstream end of the dryer, and the board at the entrance of the box removed entirely. Also testing was done involving fans connected to a solar power source. Finally, an insulated layer was added to the bottom of one prototype to both add thermal mass to the dryer and to diminish radiative heat losses from the bottom of the dryer box.

The initial comparative study results showed that sustained day light temperatures of around 130-140˚ F and 150-160 ˚ F were achieved in the metal lid prototype and the clear lid prototype, respectively. This testing proved that temperatures within the required drying range for pineapple were attainable, but that the dryer box itself did not have sufficient thermal mass. As a result, short periods of cloud cover would cause sharp internal temperature swings. To add additional thermal mass, the insulating air layer at the bottom of the dryer box was added. Two benefits were obtained through this; firstly, temperature swings internal to the box were reduced in magnitude, and secondly, due to a reduction in the amount of thermal energy that is lost out of the bottom of the dryer box due to radiative heat losses, the dryer box temperatures increased to around 160-180 F, far above the levels required to dry fruit. At this point, it was decided to work to improve airflow through the box, which was achieved through the addition of a chimney at the upstream end of the dryer and by removing the board at the air inlet. With temperature and airflow issues resolved, testing of the dryer to characterize drying times took place.

7.2. Professional Mentor/Technical Lead Affirmation

As Technical Lead for this pilot project, I attest to my involvement in the alternative analysis and acknowledge and accept responsibility for the course of this project.