Horticulture Innovation Lab

Preliminary Report on postharvest technology design, technology set-up and capacity building activities in Tanzania, Ghana, Honduras, Guatemala and Thailand

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Evaluating Small-Scale Postharvest Cooling and Drying Technologies in Various Climates

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II. Project Summary Page

This project has two major **research** objectives and one **capacity building** objective:

1) To perform a series of cool storage studies in 8 sites (2 of each RH%/Temp zones in collaboration with Horticulture Innovation Lab affiliated professionals in Africa, Southeast Asia and South America) in order to determine the performance efficiency of the ZECC compared to ambient air storage under a variety of combinations of high/low temperatures and high/low relative humidity conditions. The results will enable the UCD Horticulture Innovation Lab ME to provide accurate recommendations on low cost appropriate technologies for short term evaporative cool storage of fruits and vegetable crops.

2) To conduct solar drying studies in 8 sites (2 of each RH%/Temp zones in collaboration with Horticulture Innovation Lab affiliated professionals in Africa, Southeast Asia and South America) in order to determine the performance efficiency of the UCD solar chimney dryer compared to the traditional indirect solar cabinet dryer. Results will enable the UC Horticulture Innovation Lab M&E team to provide accurate recommendations on low cost appropriate technologies for solar drying of fruits and vegetable crops.

3) To build technical capacity in practical, low cost improved postharvest handling practices and simple technologies for cool storage and solar drying in a wide range of organizations in Tanzania, Ghana, Honduras, Guatemala and Thailand.

The research objectives were impeded by poor weather (rains, hurricanes, winds) and will need to be completed during November 2014 - February 2015. Preliminary results confirm that evaporative cool storage can provide a constant cooler, higher RH% environment and while solar drying is of limited usefulness during rainy seasons or in high humidity climates zones, the UCD solar chimney dryer performed faster and dried more produce per load than a traditional solar cabinet dryer of the same approximate cost. The capacity building objective was met and exceeded by a wide margin, with hundreds of people trained in the principles and practices associated with the two postharvest technologies that are the focus of this research project.

Keywords: Postharvest, Evaporative Cooling, Solar Drying, Capacity building

List of countries where project is taking place: Tanzania, Ghana, Honduras, Guatemala, Thailand

Total project budget: **$165,989**

Percentage of funds ($) sent to Focus Country Institution(s)
No other institutions are involved as sub-contractors in the project, but focus country cooperators were paid as independent consultants and materials/supplies for research studies were purchased in the focus countries (18% of funds).

III. Technical Background

a. Introduction

Postharvest losses of fresh fruits and vegetable crops handled by smallholder farmers in developing countries have been documented in recent years to range from 30 to 50%, depending upon the crop, largely due to a lack of appropriate postharvest handling, on farm storage and low cost food processing options. Postharvest food losses are a drain on local resources, using land, water, seeds and other inputs used during production without adding to the food supply, and often having a negative impact on food safety and food security. Through its predecessor project, Horticulture CRSP, UC Davis Horticulture Innovation Lab has funded several comprehensive projects that include postharvest aspects, and has established Regional Innovation Centers in South America, Southeast Asia and Africa, where postharvest technology innovations intended to reduce these food losses can be researched, improved and demonstrated to visiting scientists, extension workers and the local farming communities.

The need for low cost cooling and cool storage technologies

Temperature management is the single most important factor for reducing postharvest losses and increasing the shelf life of fresh produce and maintaining quality, food safety and market value. Yet electricity for refrigeration is rarely available in rural areas, and if it is available, can be unreliable and very expensive. Smallholder farmers need more appropriate options for keeping perishable crops cool during the period between the harvest and marketing.

"Cooling is considered one of the most important steps in the postharvest handling chain. Reducing the temperature of fresh produce after harvest greatly reduces respiration rate, extends shelf-life, and protects produce quality, while reducing volume losses by decreasing the rates of water loss and decay." (Kitinoja and Thompson, 2010)

A walk-in charcoal cool room, made with mesh walls filled with chunks of charcoal and kept wet via gravity fed drip system, will provide evaporative cooling under the right conditions (low humidity environment and under shade) without using electricity, but it can be time consuming and expensive to construct. We considered including a charcoal cool room in this research project, but given time and funding constraints it was determined to be impossible to include in such a short project that is planned to include so many locations. Smaller versions of this type of evaporative cooling technology have been developed and used in a variety of developing countries (including pot-in-pot storage containers, and fabric covered cabinet storage chambers) but the most famous is from India-- the Indian Agricultural Research Institute (IARI) Pusa **Zero Energy Cool Chamber,** known as the ZECC.

The ZECC is made from low quality (porous) clay bricks and sand, and is therefore low in cost and easy to construct on the farm, markets, and other appropriate links in the cool chain. Studies conducted in India indicated that the ZECC can provide cooling of up to 15°C lower than ambient air temperature, and provides a more stable temperature inside the cool chamber (less fluctuation during the day/night), which serves to preserve perishable tropical and sub-tropical horticultural crops for one week to 10 days. The ZECC was introduced in the USA in 1993 in the first edition of Kitinoja and Kader's Small-scale Postharvest Handling Practices Manual, and recently has been heavily promoted for use in low humidity climate zones and during the dry season in moderately humid regions (AVRDC, 2012; Roy, 2009; Winrock, 2009; Kitinoja, 2013; Lipinski et al, 2013, Rockefeller Fdn/GKI, 2014).

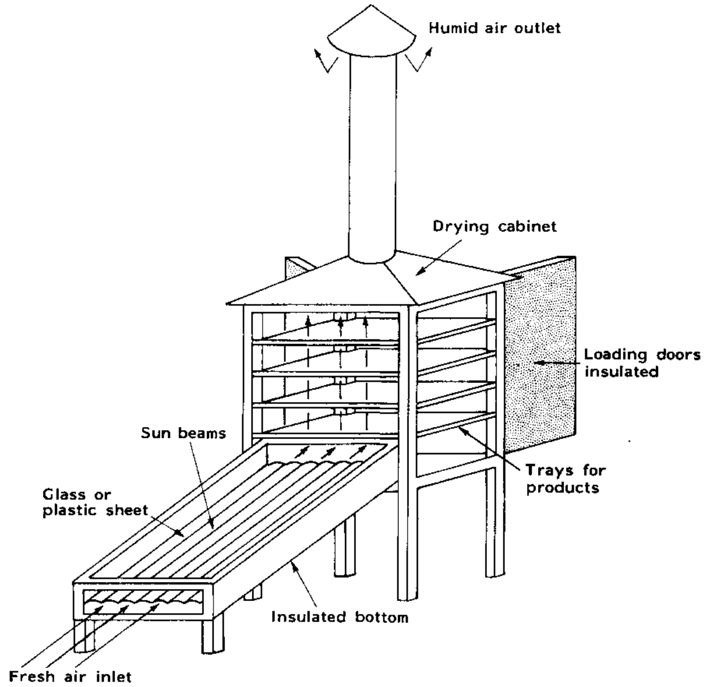
Dr. S.K. Roy, who is a retired world renowned postharvest scientist and was the inventor of the ZECC at IARI in India in the 1980s, visited Tanzania in 2012 during the Horticulture CRSP pilot project "**Extension of Appropriate Postharvest Technology in Sub-Saharan Africa: A Postharvest Training and Services Center"** and taught Lizanne Wheeler and Lisa Kitinoja to build a classic model ZECC using clay bricks and clean river sand. The photos below show the ZECC under construction at AVRDC and a completed ZECC at an MAFC site at Njiro, near Arusha in Tanzania (2012).

Initial performance in Tanzania, undertaken during 2012-13 as part of the project (PI: Diane Barrett, UC Davis; Co-PI Lisa Kitinoja, WFLO) showed positive results using a ZECC for temporary cool storage of produce in the highlands (with cool night temperatures and highly variable relative humidity). The cost of this demonstration unit (the ZECC with water tank, 6 vented plastic crates and a small thatched shade structure) is approximately $600. The cool chamber can store about 100kg of produce, keeping it fresh for up to one week during times of the year when the relative humidity of the ambient air is lower than 60%. People visiting the site to date have responded positively to the ZECC, and have already begun constructing their own ZECCs in the northern Tanzanian highlands, as well as those intended for use in many countries and under a wide range of conditions, but little is known about the performance efficiency of the ZECC in other climates or higher RH conditions.

The need for low cost processing technologies

When small farmers do not have ready access to nearby markets for their produce, or face low prices due to unusually high yields or annual seasonal gluts, having a low cost technology for drying their surplus produce is one option for reducing losses and improving access to nutritious foods in the off-season. Sun drying is a traditional practice that is widely practiced on farms and in rural areas to dry fresh produce by laying it directly in the sun. Damage is very common due to exposure to insects, heat, rain and dust.

Direct solar dryers (clear glass or plastic sheet covering vented boxes) were developed to protect the produce from dust, insects and rain, but expose the produce to direct sunlight which can cause darkening and over-drying. **Indirect solar drying cabinets** were invented in the 1970s and promoted by the UNFAO in the 1980s to overcome all these problems. They use a simple solar collector (painted black to absorb sunlight) and are designed to allow warmed air to rise through the cabinet through a series of mesh trays. The traditional design uses a wooden frame, a glass or plastic sheet for the solar collector, and double walled cabinet (made of wood, metal or a plastic covered wooden frame) with a short pipe for a chimney (UN FAO 1985, shown below):



UCD solar chimney dryer with 2 meter tall stack chimney (left) and the traditional Indirect Solar Cabinet Dryer with Solar Collector, 4 Drying Trays and small metal chimney with umbrella cap (right)

The UCD solar chimney dryer was developed in 2012 by the **Innovative Energy Solutions for Smallholder Horticulture** project, (PI James Thompson) and has been designed to use lower cost materials to construct (plastic sheeting and a simple soil berm or wood frame, and therefore less expensive than a traditional solar cabinet dryer) and with a 2m tall chimney attached to the apex of the drying area, in order to help move warm air more quickly over the drying trays (therefore holding more produce and speeding up the drying process). The photo provided here was taken in Uzbekistan, and assorted design specifications and illustrations of all the various designs for trays, tables, chimneys and coverings were provided to the PI for this project, and discussed in detail in order to decide upon a prototype model to be constructed in Tanzania and used for all the research studies.

Initial tests using a soil berm based design undertaken in California in 2012 showed positive results, and a second generation design with a raised table for the trays was developed to improve food safety aspects and better protect the drying produce from insects and rodents: "The test showed that the stack dryer required only 2 days to drop the tomato moisture content to 10% (wet basis) compared with 5.5 days for the cabinet dryer. This was a result of the stack dryer heating the air to a higher temperature and causing higher air speed past the fruit. The stack dryer was much more cost effective than the cabinet dryer, with a cost of only $7.33 per kg-day of drying capacity compared with $26.66 per kg-day for the cabinet dryer." (Innovative Energy Report October 2012)

The need for Capacity Building in postharvest technologies

Few researchers in developing countries are well educated and trained on the practical aspects of improved postharvest handling and the management of postharvest technologies, whether for research or extension purposes. The PI spent an enormous amount of time traveling to each site and working directly with the 6 teams, and providing support for set-up and construction of the 3 technologies and for conducting the experimental studies via email and skype. Sena Ahiabor, the representative of the 7th team from Anloga, Ghana, joined the capacity building sessions in Tamale for 2 weeks and received the same direct training. Hundreds of hours were spent by the PI and her supporting personnel on assisting the teams to prepare for the studies, set up and manage the weather stations, learn the experimental protocols, set-up the trials (including temperature and RH data loggers) and properly collect the data. Workshops were held on 73 days for the 144 Team members in 5 countries, which included 67 men and 77 women.

Capacity building on the ZECC

Learning to set up and manage a weather station in Sololá, Guatemala and Chiang Mai, Thailand

Although the six teams expressed their keen desire to participate in this postharvest research project, the PI found that they needed much more educational and technical support than was anticipated. Much of her time at the six sites was spent providing basic postharvest training, including how to carry out and collect meaningful data for a research project that is conducted "in the field" versus "in the lab", plan and manage the logistics in carrying out the project and teaching the teams to interact and communicate with local farmers, traders and market venders in order to be able to obtain the needed produce (of proper variety, volume, quality, maturity and timing). The teams had to do a lot of running around to find appropriate produce, so capacity building covered topics such as harvest indices, use of color charts, measuring ambient and technology temperatures and % relative humidity's with their new pocket thermometers, sorting and grading produce purchased at the markets and food safety practices.

Learning about food safety practices during preparation of chilies for solar drying experiment in Sololá, Guatemala

This project was designed to conduct simple ZECC storage vs ambient storage studies with tomatoes, and to repeat the solar drying studies using chili peppers in the same 6 sites in order to determine the performance efficiency of the second generation UCD solar chimney dryer compared to the traditional indirect solar cabinet dryer. The materials costs for the technologies were highly variable, depending upon the site, and for some countries, the required materials could not be purchased at any price. Plastic crates, in some countries (Ghana, Tanzania), were not commonly used in the PH chain and were difficult to find and costly. Traditional style produce containers and cheap, locally sourced plastic crates were often rough inside, poorly vented and without much structural integrity, plastic sheeting was sometimes white or yellowing and of minimal thickness, the available screening for the trays was of poor quality or made with inappropriate materials (galvanized and not food safe) or width/thickness (too narrow, or too thin and delicate or made with too large or too small mesh holes). Local wood products were prone to warping when cut into strips for building the trays and frames for the technologies, due to uncured wood, inappropriate wood variety and dimensions available from the local "lumber yards" and/or when the carpenter did not have access to tools or electricity to cut to more appropriate dimensions.

It was the first time that some of these teams had ever seen these technologies, and the teams had to do an inordinate amount of physical research in the local community and shops and often costly transport logistics to find the appropriate local materials. Capacity building activities covered topics such as:

- choosing or making bricks for the ZECC
- finding and buying properly sized vented plastic crates
- choosing the correct types of wood and plastic sheeting for the solar driers
- transport methods and technology construction practices (including the irrigation systems and shade structures needed for the ZECC)
- awareness that the angle of the sun can shade the dryer trays from the north or the south depending on the time of year (an effect of tropical latitudes).

Shopping for plastic sheeting in Guatemala City

Weather interfered with the collection of data at most of the sites, and the teams were generally disappointed in their initial trial results. Managing data collection in the rain and worrying about rain and wind damage to the solar driers was a constant concern. This year's annual rains came quite early in Ghana, hurricanes were raging through Central America, and Thailand's hot/wet season limited the use of the outdoor solar drying structures. Since it was the off-season for vegetable production, okra was not in season (our first choice for the ZECC studies), and tomatoes and chili peppers were very expensive and difficult to find at most of the research project sites. In some cases the teams had to travel far, and produce had to be transported many hours to reach the research project site, at a very high cost both economically and with respect to loss of produce quality. Even with the best of efforts undertaken by the local teams, the quality and maturity of the produce that could be obtained were unsuitable for conducting a large scale solar drying study.

Shopping for produce in the markets of Guatemala City, where the tomatoes available for purchase were likely to be red ripe, bruised from transport in overloaded rough wooden crates, high temperatures, and too mature to use for a week long storage study

Only the sites in Honduras at Zamorano University and Tamale, Ghana managed to conduct the full set of ZECC storage and only the Zamorano team completed the full set of 3 solar drying trials. A full set of data (3 complete trials) will need to be collected therefore, in the other 5 sites during November 2014 through February 2015. Capacity building efforts and technical support and additional funds to rehabilitate the technologies after the 7-9 months of non-use, therefore, will need to be continued through February 2015. Since the Horticulture Innovation Lab funding has been completely spent down, funds for the remaining trials will be paid for with funds that have been advanced to the teams, and supplemented, if needed by funds provided by The Postharvest Education Foundation.   Results will enable the UCD Horticulture Innovation Lab ME to provide accurate recommendations on low cost appropriate technologies for cool storage and solar drying of fruits and vegetable crops.

b. Overall Horticulture Innovation Lab Objectives Addressed

The project addressed a key issue in improving horticultural value chains in developing Countries in three regions – it focused on low cost, easy to use postharvest technologies that are designed to maintain produce quality and reduce produce losses by improving postharvest temperature management during short term storage and the use of low cost food processing (solar drying). The project contributes to achievement of one of the over-arching goals of USAID: the development of the human and institutional capability of research organizations in the countries where Horticulture Innovation Lab activities are located.

Specifically, two of the Horticulture Innovation Lab objectives are:
1. To build local scientific and technical capacity
2. To apply research findings and technical knowledge to increase small producers' participation in markets.

The project deliverables support these objectives and the intent of the Horticulture Innovation Lab by providing reliable field data from Feed the Future countries in Africa, Southeast Asia and South America, allowing them to confidently recommend appropriate technologies to a wide variety of clientele.

This research project also fits in with **Horticulture Innovation Lab's Commitment to "Leapfrog" Technologies**. It continues the work done in previous Horticulture CRSP funded projects. Conducting research on these 'leapfrog' cooling and drying technologies in a variety of climate zones will provide advanced information and postharvest tools, in an appropriate form, to stimulate and facilitate horticultural development worldwide.

Successful development and promotion of low cost cooling and drying methods will lead to:

- Increased trade of selected horticulture products in target countries
- Increased value-addition of selected horticulture products in target countries

c. Specific Project Objectives

This project had two research objectives and one capacity building objective:

Objective 1: To characterize the cooling performance of the ZECC compared to ambient air storage under varying RH/Temp climate conditions

This project was designed to perform a series of cool storage studies in 8 sites (2 of each RH%/Temp zones in collaboration with Horticulture Innovation Lab affiliated professionals in Africa, Southeast Asia and South America) to determine the performance efficiency of a 100kg size ZECC compared to ambient air storage for vegetable crops under a variety of combinations of high/low temperatures and high/low relative humidity conditions. The preliminary results in all the sites showed the ZECC provided a cooler temperature (steady and about 10 °C lower than ambient during the daytime), and a higher relative humidity environment (steady at 90 to 100%) which was suitable for fresh produce storage. Results will enable the Horticulture Innovation Lab ME to provide accurate recommendations on low cost appropriate technologies for short term cool storage of fruits and vegetable crops.

Objective 2: To characterize the drying performance of the UCD Chimney dryer and traditional indirect cabinet dryer under varying RH/Temp climate conditions

This project was designed to conduct solar drying studies in 8 sites (2 of each RH%/Temp zones in collaboration with Horticulture Innovation Lab affiliated professionals in Africa, Southeast Asia and South America) to determine the performance efficiency of the second generation UCD chimney dryer compared to the traditional indirect solar cabinet dryer. The Chimney Dryer uses six large trays (each 1 m^2). The first 2 trays serve as a 'pre-heat section', leaving 4 trays for drying the produce. The Traditional Indirect Cabinet design uses a total of 4 trays (each 0.5 m^2). Preliminary results from 3 trials in Honduras and practice trials in the other sites showed that the UCD solar chimney dryer can dry each load of produce much faster than the cabinet dryer. Results will enable the UCD Horticulture Innovation Lab ME to provide accurate recommendations on low cost appropriate technologies for solar drying of fruits and vegetable crops.

Objective 3: To build technical capacity in practical, low cost improved postharvest handling practices and simple technologies for cool storage and solar drying in a wide range of organizations/communities in Tanzania, Ghana, Honduras, Guatemala and Thailand.

Two waves of capacity building were undertaken during the project. The first activities, on basic postharvest practices, technology use and construction, experimental design and data collection protocols occurred while the PI was visiting the team at each site. The 7 teams included 67 men and 77 women for a total of 144 professionals and support personnel trained during this project.

The second wave of training was led by each team, as they shared their knowledge and experiences with their colleagues, students, local extension workers, local community postharvest chain Actors (farmers, marketers, buyers) and supervisors. During both of these types of capacity building workshops, farmers and local produce handlers, traders and marketers were invited and participated with enthusiasm. In addition, workshops were held for the many local carpenters and laborers who constructed the solar dryers.

The total number of people trained by the PI during 73 days of training events provided by this project was 1476, including 698 women, 778 men, of which 725 were students.

The total number of additional people trained in postharvest handling, storage and drying technologies by the team in Zamorano, Honduras who had been trained by Lizanne Wheeler in the construction, use and maintenance of the technologies to date is 173 during 9 days of training events that took place after the departure of the PI, which included 79 women, 94 men, 169 of whom were project leaders, administrators or elders.

This preliminary report will focus mainly on the postharvest technology designs, set-up activities and capacity building efforts undertaken by the PI and her support personnel during February through July 2014 in Tanzania, Ghana, Honduras, Guatemala and Thailand.

d. Activities and Methodology

The PI made visits to 7 sites (the 6 research sites plus once in February to Arusha, Tanzania for building a prototype of the UCD Chimney dryer and preparing instructions for cooperators) to set up the ZECC and solar drying technologies and the weather stations with local collaborators, and provide hands-on workshops on construction and use, experimental protocols and data collection procedures.

In March the PI attended the Horticulture Innovation Lab annual meetings in Honduras, where she first met face-to face with the cooperators who were in attendance, set up the three technology demos and held a series of demonstrations and discussions.

The 6 sites for data collection were selected based upon recommendation from the Horticulture Innovation Lab ME leadership team and Regional Innovation Center leaders. The sites represent a wide range of varying RH% and ambient air temperatures experienced during specific times of the year. For each site, detailed records of costs for materials and construction were prepared.

It was planned for data to be collected twice in Tamale, Ghana (where the climate was to change from high to moderate temperature when the rainy season began in May/June), but due to the weather difficulties when the rains started in March, only one set of data on solar drying will be collected during the moderate RH/high temperature conditions expected in late 2014 to early 2015. The first ZECC "melted" away when it was saturated with water, according to maintenance protocol, (the clay bricks had not been fired) and new blocks, made with a specific combination/team tested recipe of cement and river sand for adequate porosity, had to be developed and manufactured so a second ZECC could be built at the SARI/UDS postharvest demonstration site. The PIs luggage, in which the plastic sheeting for the solar dryers was being carried to Ghana, was "lost" for nearly 10 days by the airline, so the materials for the solar dryers had to be sourced locally, at high cost and with great difficulties. During the first trials, due to the poor weather conditions, the produce decayed in the ZECC (and was attacked by rodents) and got moldy in the solar dryers.


The first "melted" ZECC in Tamale, Ghana

The second ZECC in Tamale, constructed using custom made porous cement and river sand blocks (used the same mold as was used for the clay bricks)

Anloga, Ghana was originally included as a separate site, but the weather conditions near the southern coast were so similar to the rainy season in Tamale during the project period that the technologies were not set up there, and the collaborator from Anloga, Sena Ahiabor was invited to join the group for the intense two week capacity building training in Tamale during April 2014. Sena was contracted to provide detailed weather and climate information for Anloga and prepared cost spreadsheets providing an accurate estimation of costs of the materials and construction of the technologies in Anloga.

During March – July 2014, this Focus project set up 6 new ZECCs in Ghana, Honduras, Guatemala and Thailand, and provided hands-on capacity building in their construction, use and maintenance. The original project plan was to work in 7 different sites (collecting data twice in Tamale as the seasons changed), but due to time and cost considerations, plus uniformly "poor weather" conditions during March through July, it was possible to work in only six of the sites. Wherever possible the 6 trained teams, working closely with Lizanne Wheeler, performed the first trials under her supervision for the planned series of cool storage studies. They all used the same crop (tomatoes harvested or purchased at the pink stage) to determine the performance efficiency of the Zero Energy Cool Chamber compared to ambient air storage under a variety of combinations of high/low temperatures and high/low relative humidity conditions. Poor weather and heavy rain interfered with the collection of data in most of the sites, since the project got a later start than first planned in late 2013 due to paperwork issues, and it was then requested that Lizanne attend the annual meeting for Horticultural Innovation Lab in Honduras during mid-March. It was a good opportunity to meet with many of the project collaborators. This was also the site of the Honduras project TEAM and these technologies were built and demonstrated, discussed, presented by the PI to all of the annual meeting participants during a site field visit to Zamorano.

This year's annual rains arrived 5 weeks early in Ghana, hurricanes were raging through Central America in May, and Thailand's hot/wet season during June/July limited the use of the outdoor storage structures. The weather was so bad that some of the technologies were damaged by high winds and down-pouring rain. In Bangkok, Dr. Jate Sathornkich had to keep the solar dryers inside the unused greenhouse where they had been built. He felt that if they had been put out they would have been damaged, and he was surprised that the ZECC and its shade structure had not been damaged. Since it was the off-season for vegetable production, tomatoes were very expensive and difficult to find at most of the research project sites. In some cases fruits had to be transported from farms or markets many hours away to reach the site, at very high cost. Even with the best of efforts undertaken by the local teams, the quality and maturity of the fruits that could be obtained were determined by the PI to be unsuitable for conducting a storage study.

Only the site in Honduras at Zamorano and Tamale, Ghana managed to conduct the full set of ZECC trials. Data will need to be collected, therefore, in five sites during November through February 2015. Results will enable the UCD Horticulture Innovation Lab ME to provide accurate recommendations on low cost appropriate technologies for short term evaporative cool storage of fruits and vegetable crops.

Tanzania (Arusha) – for prototype development/preparation of materials list, instructions, workshop plans for the UCD solar chimney dryer
Ghana (Tamale and Anloga, which were combined into one site)
Honduras (Tegucigalpa/Tegus where Zamorano University is located)
Guatemala (Guatemala City and Sololá)
Thailand (Bangkok and Chiang Mai)

Predicted Climate Characteristics of the 7 sites during April-July

	RH%	Temperature	Data collection sites			
ZONE			March	April	May-June	July
1	high	moderate		**Anloga Sololá**		
2	moderate	high	**Guatemala City**		**Tamale**	
3	moderate	moderate		**Bangkok**	**Tegucigalpa**	
4	low	high	**Tamale**		**Chiang Mai**	

In reality, the expected RH/Temp combinations predicted for Zone 2 and 4 did not occur during the project period, and the actual climate characteristics put 3 of the sites into Zone 1 (high RH/moderate temperature, the least likely to result in successful evaporative cooling or solar drying) and the others in Zone 3 (moderate RH/moderate temperature) or in a new unpredicted Zone of high RH /high temperate. Zone 5 also resulted in very poor quality results during the set up /practice trials, and in all cases, the ZECC and solar drying research studies were put on hold.

Actual Climate Characteristics of the 7 sites during the PI visits and planned trials in April-July

	RH%	**Temp-erature**	**Data collection sites**			
ZONE			March	April	May	June/July
1	high	moderate		**Anloga** 28-30 C 75-95% RH		
1	high	moderate		**Tamale** 28-45 C	**Sololá** 14-22 C	**Tamale** 25-48 C

				35-95% RH	65-100% RH	35-100% RH
3	moderate	moderate			**Guatemala City** 17 -30 C 50-90% RH	
3	moderate	moderate	**Tegucigalpa** 25-32 C 30-65% RH	**Tegucigalpa** 18-32 C 40- 100%	**Tegucigalpa** 15-32 C 20-70%	
5	high	high				**Bangkok** 26-36 C 60-100% RH
5	high	high				**Chiang Mai** 23-35 C 50-98% RH

During November 2014 through February 2015, the predicted climate characteristics for the locations of the 6 teams are more suitable for completing the planned data collection across a broader range of the climate zones. The 5 remaining sites can provide data in which the other three climate Zones are well represented. The zone that will not be further studied is Zone 1 (with high RH/moderate temperatures) which resulted in a lot of moldy produce and abandoned trials during the capacity building period.

Predicted Climate Characteristics of the 5 sites during November through February

ZONE	RH%	Temperature	Data collection sites
1	high	moderate	-
2	moderate	high	Guatemala City No rain, fog 50% of days, max T 30-32 C
2	moderate	high	Bangkok Less than 1mm rain/day, coastal location Max T of 37-38 C
3	moderate	moderate	Sololá No rain, fog most days, high altitude, cool nights Max T of 26-28 C Tegucigalpa (Zamorano campus) Completed in May 2014
4	low	high	Tamale No rain Max T of 38-39 C
	low	high	Chiang Mai Less than 1mm rain/day Max temp of 34 – 38 C

The type of produce used for each of the experiments was selected to provide reasonably rapid results and is commonly found in the traditional diets of the population in all three regions. For the ZECC trials, **tomatoes** were stored for one week (during which time they will lose weight, shrivel, become over-mature/over-ripe and/or show signs of decay if storage temperatures are too high for successful storage). Additional crops were considered by each of the local teams for use in the cool storage studies during April through July, but the availability was extremely limited, quality was poor and costs for purchase and transport were prohibitive.

Produce will be stored in the ZECC for one week and compared to ambient air storage (control). Ambient temperature storage conditions in all the sites was under deep shade, outdoors, in vented plastic crates (a typical traditional "improved" practice for short term storage). The experimental design was worked out in detail in collaboration with the postharvest specialists of Horticulture Innovation Lab leadership team and WFLO's senior technical advisor. Capacity building activities included the materials and methods required to carry out this research. Actual times of set-up and data collection were adjusted based upon weather conditions and work schedules and temperatures/RH were measured continually via data loggers.

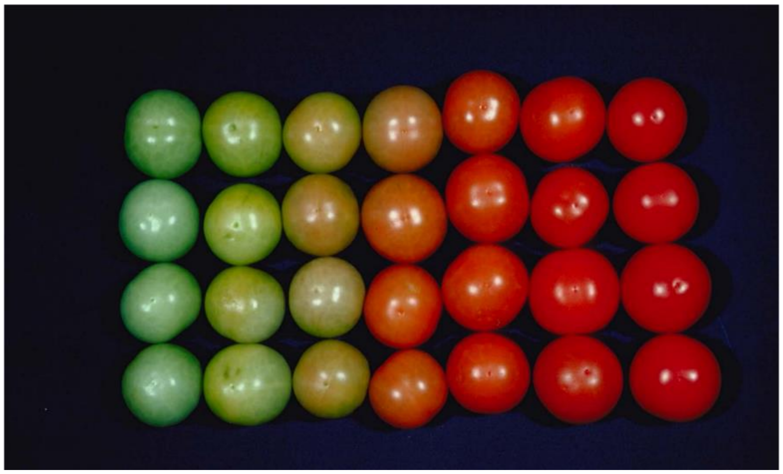
Research design: ZECC

Treatments:	2	Control (ambient temp storage), ZECC cool storage
Sites:	8	2 sites per 4 zones (Temp/RH zone 1 , Temp/RH zone 2, Temp/RH zone 3, Temp/RH zone 4)
Crops:	3	Tomatoes
Times:	3	day 0, 7
Replicates:	3	

Measurements: Experimental Data to be collected

1. Temperature inside the chamber & ambient
2. Pulp temperature of product, inside the chamber & ambient
3. Relative Humidity, inside the chamber & ambient
4. Wind speed, wind gusts, ambient
5. Solar Radiation, ambient
6. Quality of product over time, (general appearance, decay, freshness, % water loss)
7. Product load (kg/m3)

Produce maturity rating scale for tomatoes (7 points, from MG to full red)

 Maturity scale

Visual quality rating scale for tomatoes
9= excellent, 7= good, 5= fair, 3= poor, 1= extremely poor

For the solar drying trials, **sliced hot chili peppers** were dried in both types of solar dryers. Chilies do not require pre-treatments to prevent browning and should dry fairly quickly under most climate conditions (compared to high sugar content crops that can attract ants or vegetable crops that require blanching as a pre-treatment to prevent discoloration). Produce was dried until it reached approximately 10% moisture content based upon its original dry weight (determined via sampling at 5 hour intervals, approximately 17% of initial fresh weight). The experimental design was worked out in detail in collaboration with the postharvest specialists of Horticulture Innovation Lab leadership team and WFLO's senior technical advisor. Capacity building activities included the materials and methods required to carry out this research. Additional crops were considered by each of the local teams for use in the solar drying studies during April through July, but the availability was limited, quality was poor and costs were prohibitive. Actual times of data collection were adjusted based upon weather conditions, work schedules, observed drying rates, etc.), and temperatures/RH were measured continually via data loggers.

Research design: Solar drying

Treatments:	2	Control (traditional indirect solar cabinet dryer), UCD chimney dryer
Sites:	8	2 sites per 4 zones
Crops:	2	Chilies (slices)
Times:	5	hour 0, 5, 10, 25, 31 (ideally)
Replicates:	3	

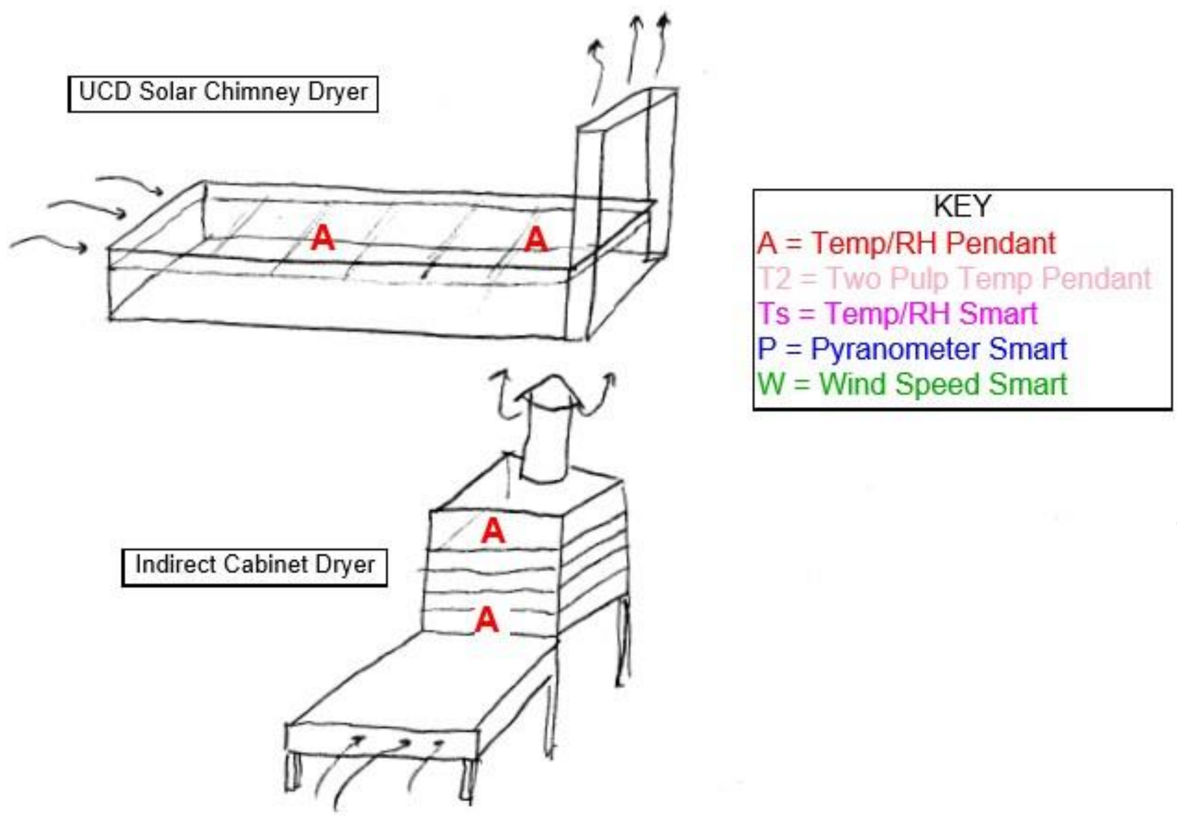
Measurements:

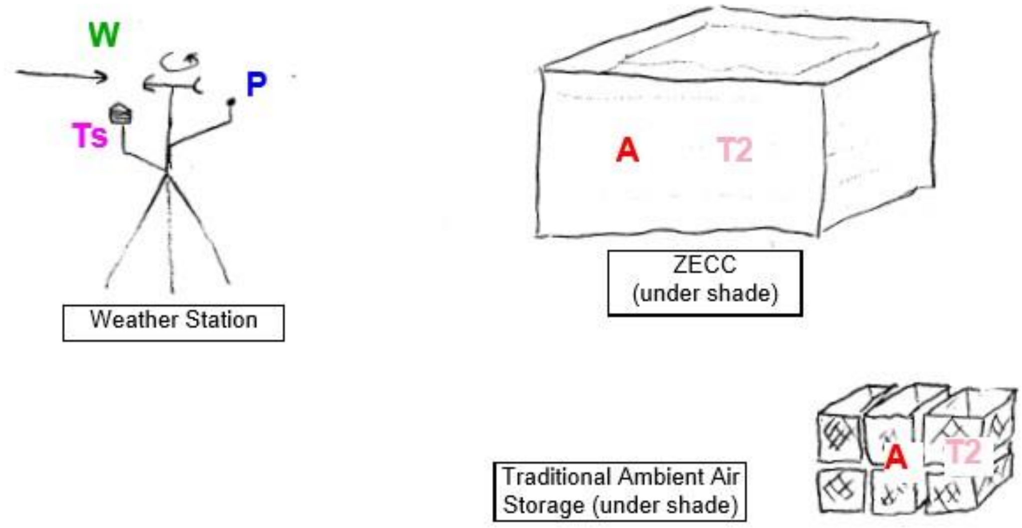
1. Temperature, inside the cabinet/tunnel, at outlet & ambient
2. Relative Humidity, inside the cabinet/tunnel, at outlet & ambient
3. Solar Radiation, ambient
4. Wind speed, wind gusts

5. weight
6. % water loss over time in product
7. Quality of product (general appearance, color)
8. Product load (kg/m^2 or m^3)
9. Smoke test to measure air flow from entrance to exit of each dryer

Visual quality rating scale for chili peppers
9= excellent, 7= good, 5= fair, 3= poor, 1= extremely poor

The following is a diagram of the positions for the HOBO data loggers used in the solar driers and ZECC research studies.





The complete protocols for the experiments, and sample data collection worksheets can be found in Appendix A.

These final results of these research studies will assist in answering many interrelated questions:

Small Scale Cooling Technologies: ZECC

1. When and where is ZECC appropriate?
2. RH considerations and day/night temperature swings for location decision
3. Materials utilized (characterize the size and material of bricks, sand cleanliness and diameter, shade structure design, varying local materials used for cover of ZECC, wetted jute sacks over cover differ in moisture content, etc., all may differ)
4. How will the Water source and application be replicated? (bucket, sprinkler can, hosepipe with gentle nozzle sprayer, water bag, drip hose (type/ design?), 250plus L tank: filled by hand or directly replenished by pipe and valve?)
5. Determine ET data at each location and changes through season and how will the “irrigation scheduling” be determined? What quantity and frequency?

Comparison of Solar dryers: Traditional Cabinet and UCD Chimney Type

1. Are the results really different? Which is the better design and why?
2. What are the costs for construction at each in the 7 locations?
3. Do these dryers result in too great a discoloration of final product?
4. What are the effects of sun, cloudy and partly cloudy conditions? How are they affected by partial rain days and partial high intense sun days?
5. Which dryer works better in high humidity environments?

6. What are the differences in the two dryer site requirements with respect to physical area needed (additional considerations of shade obstructions, solar alignment which may change depending on location and time of year and security).

Detailed descriptions of the three postharvest technologies constructed for the focus project

All three technologies ready for research studies in Sololá, Guatemala, including weather station

Zero Energy Cool Chamber

A low cost porous brick and sand evaporative cool chamber, approximately 1.3 m^3 volume, using no external energy. Six vented plastic crates (stacked 3 x 2 high) are used as the basis for determination of the dimensions for construction (the exact size will therefore depend upon what type and size of crates are available locally).

A floor of bricks is laid, and a double walled brick chamber is constructed, leaving about 5cm of space between the walls. Sand is filled in and kept moist between the double brick walls and a fitted top cover for the inner chamber keeps the cool moist air within the chamber, cooling the stored product as the water evaporates from the outer side of the brick walls. Up to 100 kg of fresh produce can be stored inside the ZECC in the 6 vented plastic crates.

A shade structure made of local materials is constructed over the ZECC, using four poles to support the shade roof. The shade structure is an essential component as it protects the ZECC from direct sun and reduces heat gain from solar radiation. It is important to locate the ZECC in an area where there is no risk of flooding and free air movement is able to surround the chamber and carry away the heat via the principal of evaporative cooling.

Maintenance of the ZECC requires keeping the porous bricks and sand saturated by watering twice per day (dependent on ET) or setting up a gravity fed drip system.
(Original source: S K Roy)


ZECC construction in Ghana


ZECC construction in Honduras

A completed ZECC in Honduras, with cover, water bag and thatched shade structure. A shade curtain was later attached to the sunny side.

Materials list

ZECC materials list (Tamale example)	
river sand (2 large drums)	0.36 cubic meters
Vented plastic crates	6
Bricks or blocks	600
teak poles for shade structure	10
plastic watering can	1
Rope for tying on mats	7
zaana mats for shade	4 bundles
Plastic sheet to cover crates	116 x 64 cm
Local neem sticks tied together for cover	Match size to ZECC
Jute sacks for cover	Match size to ZECC

Tools needed for ZECC construction:

- machete to cut bricks
- shovels and rakes for leveling ground and pad
- wheel barrow for hauling sand and bricks

See Appendix B for TEAM GHANA's detailed and informative Powerpoint presentation on ZECC construction.

PI Note: Irrigation systems and watering methods differed widely by team. Some teams used a 250L water tank on concrete blocks support, with drip line Honduras had a 100 L water bag with drip line, Guatemala City had a sink nearby, in Sololá used a 1100L tank with drip line purchased on special, BKK had a used tank, in Chiang Mai we had a drip hose connected to a spigot that was close by.

Traditional indirect solar drying cabinet
The indirect drier has three main components:

- external air heater (solar collector)
- drying cabinet with its trays
- air circulation and evacuation device

External air heater. A good air heater consists of an enclosure that is rectangular in cross section. The top of the enclosure is a transparent glass or plastic sheet allowing the sun rays to heat the black painted bottom.

The drying cabinet. Can be a simple cupboard shaped chamber with a door. The cabinet can hold several trays (typically 3 to 6) placed on racks. The hot air from the external air heater enters the cabinet through an opening at the bottom, rising through the mesh trays with the products, as it exits towards the top.

Humid air exit. The top of the cabinet has a device for exit of the hot humid air with possibility of recycling in case the air is not completely saturated with humidity. Extraction of air can be achieved through:

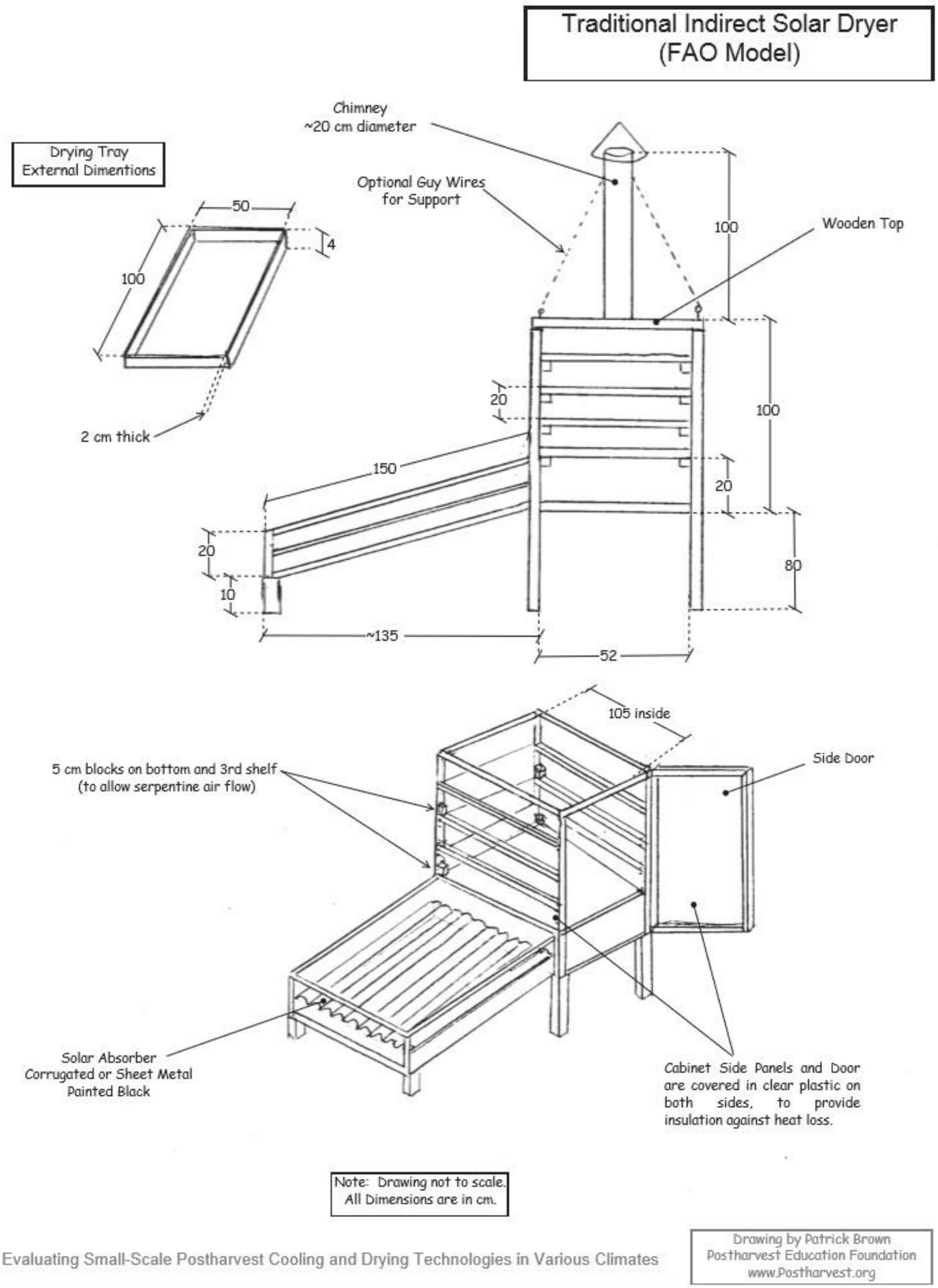
- a chimney with an umbrella cap (natural extraction)
- a chimney with a wind ventilator
- an electrical fan

Controls and analysis (indirect driers). It is considered advisable to check the temperature and humidity of heater inlet and outlet air, air in contact with the products and drier outlet air.
In addition, residual humidity of dried products should be analyzed and total weight of ingoing and outgoing products should be recorded.

Source: Expert consultation on planning the development of sundrying techniques in Africa. Proceedings of the Expert Consultation on Planning the Development of Sundrying Techniques in Africa. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS Rome, 1985 http://www.fao.org/docrep/x5018e/x5018E00.htm#Contents

Indirect solar cabinet dryer constructed in Chiang Mai, Thailand showing chimney with a “Chinese cap” style cover.

Constructing the indirect cabinet dryer in Guatemala City, late into the night


Traditional Indirect Solar Dryer
(FAO Model)
Drying Tray
External Dimentions
50
4
100
2 cm thick
Chimney
~20 cm diameter
Optional Guy Wires
for Support
100
Wooden Top
20
100
150
20
20
80
10
~135
52
105 inside
5 cm blocks on bottom and 3rd shelf
(to allow serpentine air flow)
Side Door
Solar Absorber
Corrugated or Sheet Metal
Painted Black
Cabinet Side Panels and Door are covered in clear plastic on both sides, to provide insulation against heat loss.
Note: Drawing not to scale.
All Dimensions are in cm.
Drawing by Patrick Brown
Postharvest Education Foundation
www.Postharvest.org

Materials List

Traditional Cabinet Dryer Materials List (Bangkok example)

Item	Cabinet model	total meters	comments
Black Paint for Traditional Dryer	1		to paint bottom of solar heat collector
Thinner for paint	1		this is common practice in Thailand
Lumber wood 1 1/2 * 3 inch 2.5 m length	4	10	
Lumber wood 1 1/2 * 3 inch 3 m length	2	6	
Lumber wood 1 * 2 inch 2 m length	15	30	
Plywood 10 mm thick 120 * 240 cm	1		often only sold in one large piece
corrugated metal sheet	2		if narrow sheets-- buy two and overlap
Screw 2 inch	200		
Screw 1 1/2 inch	300		
Staples	hundreds		
Galvanized metal chimney with "Chinese hat" cap	1		
Butterfly hinge screw for Cab dryer	1		
door latch for CAB dryer	1		
net for trays (42 inch width)	3 meters	3	
UV Plastic (3 m width)	4 meters	4	
silicon caulking tube	1		rain leaked in around chimney pipe and boot
wire for "guy wires"	4 meters	4	to hold up chimney in inclement weather

Needed tools (would need to purchase if not already available)-- critical: and dependent on project site

staple gun and staples

pencil

paint roller or paint brush

hand saw or power saw

screwdriver

tape measure

hammer

level

drill, drill bits

caulking tube dispenser gun

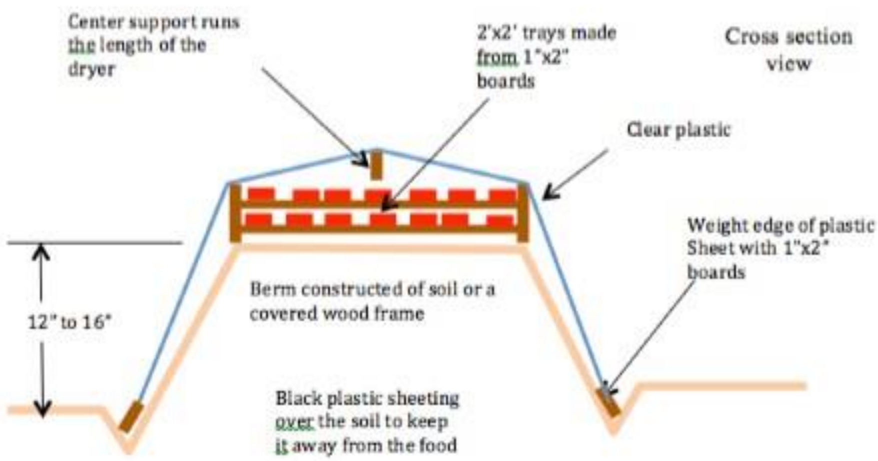
electricity

Some sites used nails instead of screws

UCD solar chimney dryer
"Horticulture Innovation Lab researchers have been testing a new solar drying design that improves efficiency and reduces drying time for fruits and vegetables. A raised bed (or wooden frame) is covered with black plastic or dark-colored row cover material. The product is placed on wooden trays along the length of the raised bed or the wood frame. A clear plastic sheet placed over the trays traps the sun's heat and drives water out of the fruits or vegetables.

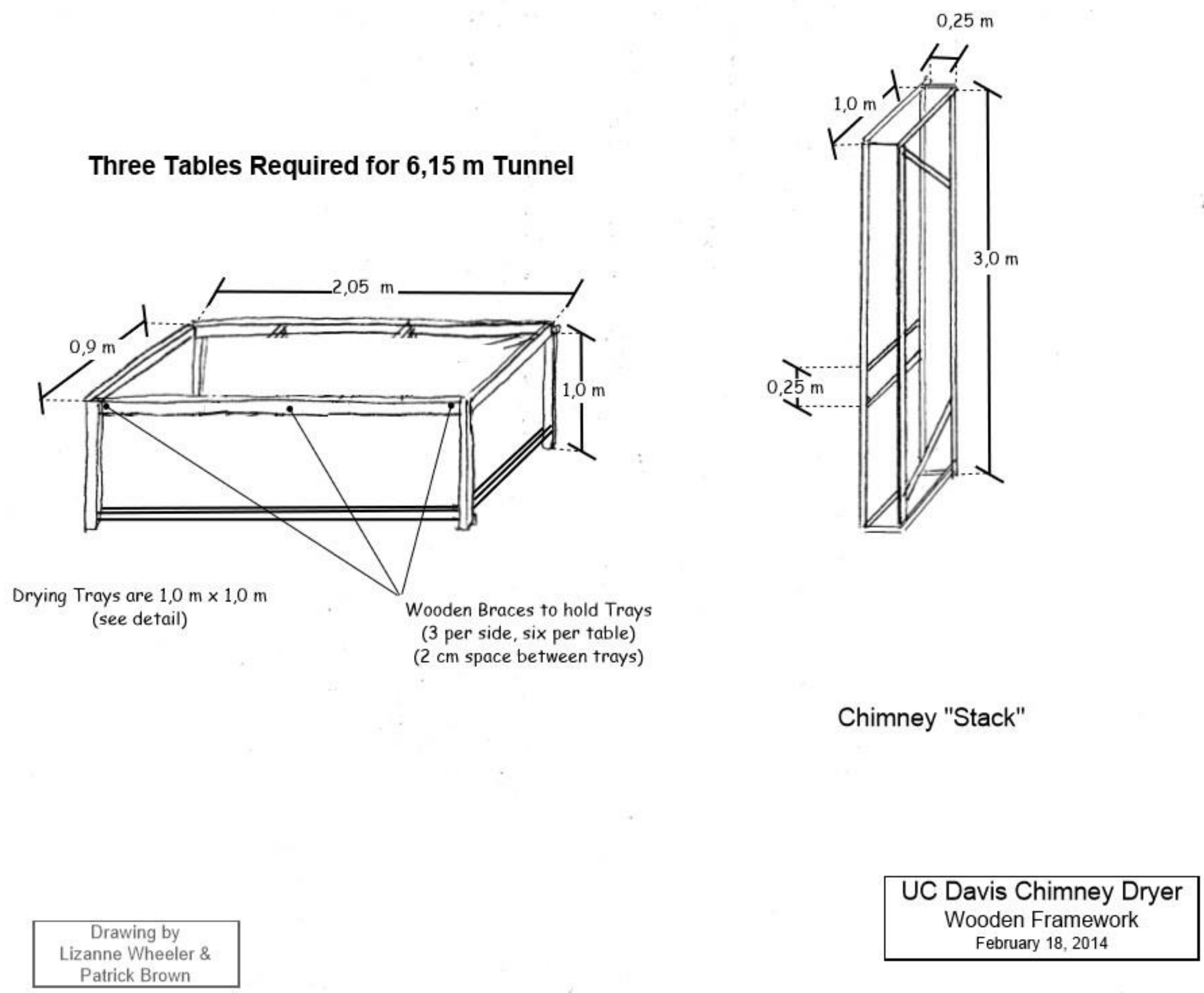
The basic materials needed are; one sheet of 4 mil polyethylene film 30 x 8 feet, a similarly sized sheet of black nonwoven fabric (or plastic, similar to row cover material), 2" x 2" x 8' lumber (x7), 1" x 4" x 8' lumber (x6), 11/2 - 4' x 8' sheets, 3/8" exterior plywood, 50 ft2 - plastic mesh, 3d galvanized nails ½ kilo, one box of 3/8" staples and stapler.

A wooden frame should be constructed to keep the produce off the ground, and to make lifting heavy trays easier. The frame will be 6 meters long and 1 meter wide at the top and 2 meters wide at the bottom. This angle is important as the heat under the plastic rises and will pass over the fruit at the highest point where the air is the hottest. Construct the chimney the same way as you would if the dryer were on the ground (…at the northern end of the mound, four stakes are driven into the ground to form a chimney that is 50 cm wide, 30 cm deep, and 2 meters high), except make sure to make it 2 meters higher than the top of the drying area. Connect the frame to the chimney making sure to leave to space for the air to flow over the produce and out the chimney."

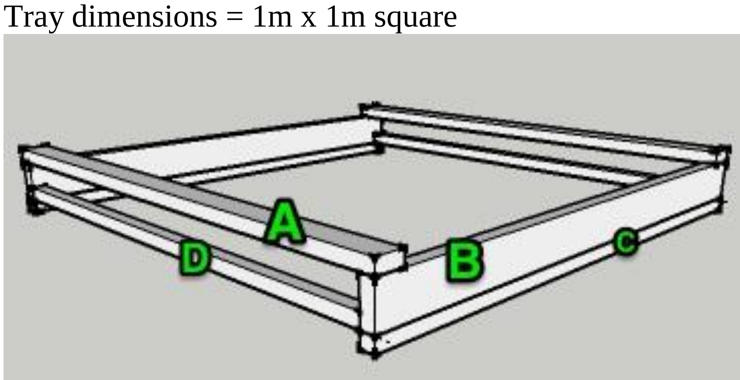


Source: UCD Solar Drying Manual 011014

For this project, several modifications were made during the design phase and prototype construction in Tanzania. The trays were 1m x 1m and arranged in a single layer although 12 trays were constructed and trialed. It was decided with the Horticulture Innovation Lab ME team that it would be too expensive and time consuming and heavy for the project teams, so 6 trays were decided upon for the research project technologies to be constructed in all the other sites. The chimney was 1m x 0.25m x 3m tall (2m taller than the table). The tables were made in 3 sections to make it easier to assemble, and disassemble for downtimes and move the dryer to the site (each 1.0m tall, 0.9m wide, 2.05m long). The tables had wooden blocks that acted as braces attached on the outer edges of the tables (over the black plastic) and flush with the table top to hold the 1m wide trays. A lightweight net was placed across the air entry point and over the exit of the chimney (to prevent insects from entering the dryer).



Tray dimensions = 1m x 1m square



Wood Frame and $1m^2$ trays for UCD chimney dryer. This shows the plywood between the table and chimney, which we got from the original Uzbekistan photo that MS Reid gave to the PI during proposal development. We decided after prototyping in TZ that it was expensive and not needed.

UCD chimney dryer with 6 trays in Chiang Mai, Thailand

UCD chimney dryer covered in plastic sheeting in Tanzania

Materials list

UCD Solar Chimney Dryer Materials List (Bangkok example)

Item	UCD model	total meters
Lumber wood 1 1/2 * 3 inch 2 m length	21	42
Lumber wood 1 1/2 * 3 inch 3 m length	4	12
Lumber wood 1 * 2 inch 2 m length	8	16
Lumber wood 1 * 2 inch 3 m length	12	36
Screw 2 inch	100	
Screw 1 1/2 inch	200	
Staples	hundreds	
net for trays (42 inch width)	7 meters	7
Black Plastic (2 m width)*	12 meters	12
UV Plastic (3 m width)*	18 meters	18
wire for "guy wires" to hold up chimney	4 meters	4

Notes * widths of plastic will vary by location, and sometimes the sheets will need to be pieced together, which requires the use of high quality tape

Needed tools (would need to purchase if not already available)—
critical: and dependent on project site

staple gun and staples
pencil
hand saw or power saw
screwdriver
tape measure
hammer
level
drill, drill bits
electricity
Some sites used nails instead of screws

Complete instructions for construction of each technology are provided in Appendix B.

Preliminary research results

1) Initial trials for each of the teams were not carried to completion, but there was some useful data that can be gleaned from the exercise in all 6 sites. Since the weather conditions across all the sites were consistently humid and rainy, the first batch of data provides good insight into the results in Zone 1 and Zone 5.

ZECC trials -- Honduras, Sololá, Guatemala City, Bangkok, Chiang Mai
Three full trials were conducted in Ghana and Zamorano, and practice trials were conducted in the other four sites.

Practice ZECC trials
Results after one week of storage in the ZECC vs Ambient air (April – July 2014)

Trial site	Temperature and RH%	Weight loss	Maturity	Visual Quality
G.City	17-30° C; 50-90% RH	Weight loss less than 2% in ZECC; about 5% in Ambient storage	Initial = breaker to pink Final = pink to red for ZECC, light red to red for Ambient	Not much difference visually; ZECC stored tomatoes were more firm than Ambient.
Sololá	14-22° C; 65-100% RH	No weight loss in ZECC; no data for Ambient	Initial = pink Final = light red to red in ZECC; no data for Ambient	Visual quality in ZECC was Excellent; no data for Ambient
Bangkok	26-36° C; 60-100% RH	Weight loss less than 5% in ZECC; 5 to 10% in Ambient storage	Initial = pink Final = pink to light red for ZECC; light red to red for Ambient	Very good to fair in ZECC; Good to extremely poor in Ambient air
Ch. Mai	23-35° C; 50-98% RH	Less than 3% weight loss in ZECC; 5% weight loss in Ambient	Initial = mix of MG to red Final = pink to red for both	Fair for ZECC but the ZECC tomatoes had more firmness; Fair to extremely poor for Ambient

Initial maturity and temperature (23C) for practice ZECC trial #1 in Guatemala City. The tomatoes were greenhouse grown and very expensive.

Results for ZECC practice trial #1 in Guatemala City


Results for ZECC practice trial #1 in Bangkok showing good to excellent quality tomatoes

Performance notes on the ZECC

- Stabilization of day/night temperatures inside the cool chamber
- Very high RH% inside the ZECC is perfect for fresh produce
- Firmness is better for ZECC stored produce compared to ambient storage
- ZECC under shade in breezy location is a generally cooler spot than typically used for temporary ambient temperature storage often inside homes with no circulation and higher inside temperatures
- The teams are already using the ZECCS for storage


Screen cover to prevent rodents in Guatemala City, Guatemala

Solar drying trials – Honduras, Ghana, Sololá, Guatemala City, Bangkok, Chiang Mai
Three full trials were conducted in Honduras (see the next section on completed studies), and practice trials were conducted in the other four sites.

Practice Solar drying trials
We have preliminary data from 5 sites, in summary showing that the UCD solar chimney dryer was faster overall as compared to the traditional cabinet dryer. Quality was generally good, with the exception of the trials where rain leaked into the dryers.

Results of UCD solar chimney dryer vs traditional indirect cabinet dryer (April - July 2014)

Trial site	Drying time to 10% moisture (hours)	Visual Quality	Comments
Tamale	Very rapid drying for the first few hours in both dryers. 25 hours for UCD solar chimney dryer; 47 hours for Cabinet dryer	Excellent for both dryers	Weather deteriorated so 2nd and 3rd trial could not be mounted
G.City	Difficult to say, campus was closed on Day 2 and 3, UCD solar chimney dryer was found dry on first reading of Day 4. Cabinet dryer samples found dry on Day 5 thru 7.	Very good for UCD solar chimney dryer; Good for cabinet dryer.	Dryer construction delayed the start after chilies were prepared for drying Day 0), Started raining on Day 1
Sololá	Very rapid drying for the first few hours in both dryers. 20 hours for UCD solar chimney dryer; no data for Cabinet dryer	Very good to excellent for UCD solar chimney dryer	Rain leaked into the cabinet dryer, re-wetting the drying chilies on Day 3; trial for cabinet dryer was stopped
Bangkok	Similar drying rate, both dry by 25 hours	Both extremely poor visual quality	Unattractive product
Ch. Mai	UCD solar chimney dryer samples dry in 22 to 31 hours; Cabinet dryer takes 46 to 53 hours to dry	Good for UCD solar chimney dryer; Fair for cabinet dryer.	Half of the samples in the UCD dryer were fully dry within 8 hours.

Sample of very good to excellent quality dried chilies from Sololá practice trial (UCD solar chimney dryer)

Cabinet dryer tray loaded with sliced chilies in Bangkok

Unattractive product after drying in both types of solar dryers

Mold on chilies in solar Cabinet dryer, after rains in Tamale, Ghana

In order to successfully complete an entire set of research trials, we need to have consistent:

- weather
- initial produce quality and quantity
- produce price
- handling practices for preparations
- access to labor (avoid holiday seasons, weekends)
- management of the technologies
- team members (kept changing as members get reassigned)
- access to the research site (security locked staff out, guard dogs blocked access)

2) Completed trials from Zamorano University (Honduras) and Tamale (Ghana)
A complete set of research trials were completed for both the ZECC/ambient and the Solar dryer comparison experiments in Honduras and a complete set for the ZECC/ambient study was conducted in Tamale. The raw data (HOBO datalogger files of temperature and RH%, completed Excel data worksheets on weight, maturity and quality) and photos of the samples are provided in Appendix C.

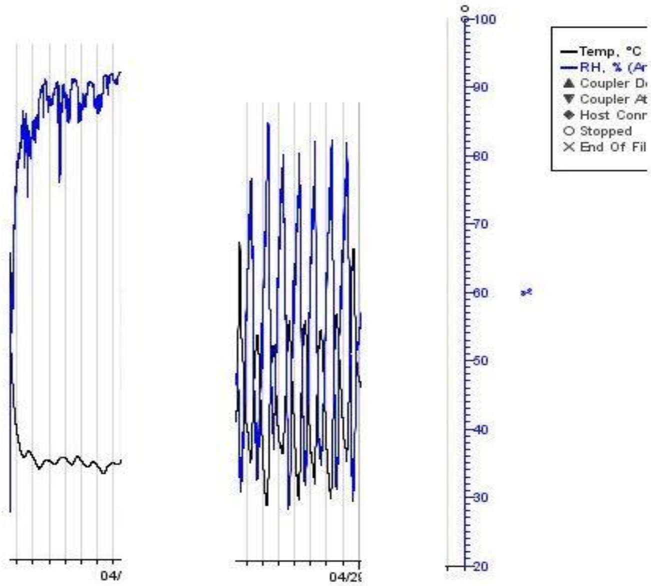
The results in the ZECC vs Ambient air were highly variable, the differences based mainly upon the very different weather conditions experienced during the trials. Initial temperatures of the produce in both sites was approximately 30 °C, and the weather was moderate to rainy. In each case, three samples were gathered for each of 4 plastic crates. The visual quality of the ZECC stored tomatoes in Honduras was generally good, and the firmness (as subjectively noted by the team) was more firm than that of the Ambient air stored tomatoes. The tomatoes available in Ghana that were suitable for conducting storage studies were quite limited.

ZECC studies

Results after one week of storage in the ZECC vs Ambient air in Honduras (March 2014)

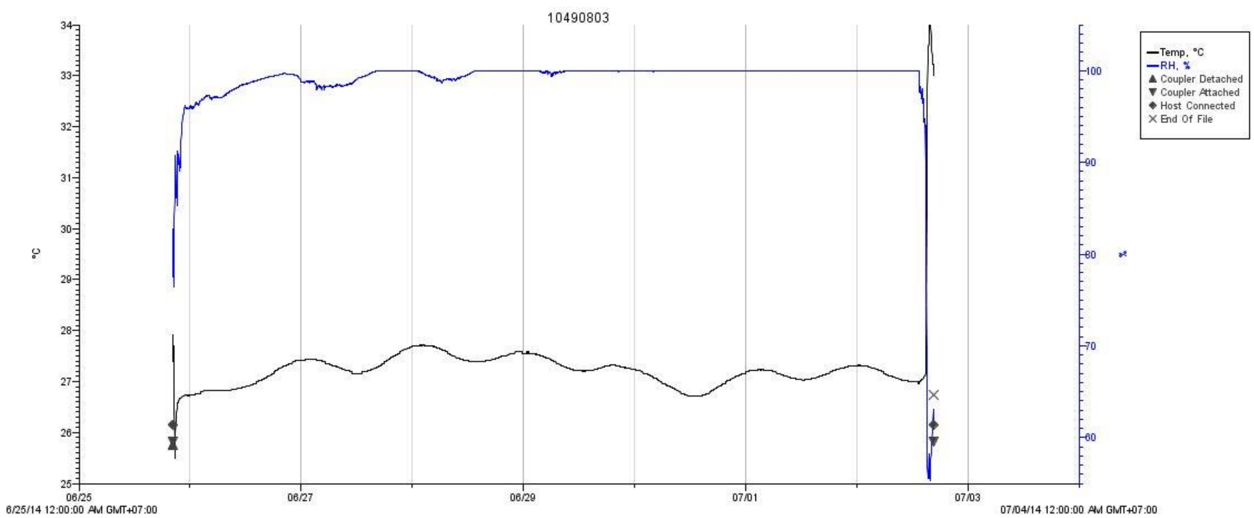
Trial	Temperature and RH%	Weight loss	Maturity	Visual Quality
1	ZECC Temps of 20-23°C was approx. 10°C lower than Ambient temps during the day ZECC (steady at 90-95%) and Ambient air of high relative humidity, rainy weather (Ambient day/night swings from 20% to 90%)	No difference in initial and final weights in ZECC or Ambient	ZECC and Ambient were both 100% full red	Good in ZECC; fair to poor in Ambient air
2	--same--	No weight loss in ZECC; 5% weight loss in Ambient	ZECC and Ambient were both 99% full red	Good to excellent in ZECC; good to fair in Ambient air
3	Ambient air was lower RH% than ZECC, very large daily swings	2% weight loss in ZECC; 13% weight loss in Ambient	ZECC and Ambient were both 100% full red (note: 10% of the tomatoes were green, did not mature at all, across all samples)	Good to fair in ZECC; fair to poor in Ambient air

The following graph illustrates the RH% and temperatures found in the ZECC during Trial 3.



ZECC Ambient
Steady RH% and temperature inside ZECC vs Ambient swings (April 21 thru 29, 2014), Zamorano, Honduras

In Chiang Mai, even though the weather was not cooperative for conducting a full set of trials, and ambient temperatures were very high, the ZECC dataloggers provided an excellent example of the steady, cooler temperatures during the day and night, and high RH% inside the chambers, both of which are very good conditions for fresh produce storage.

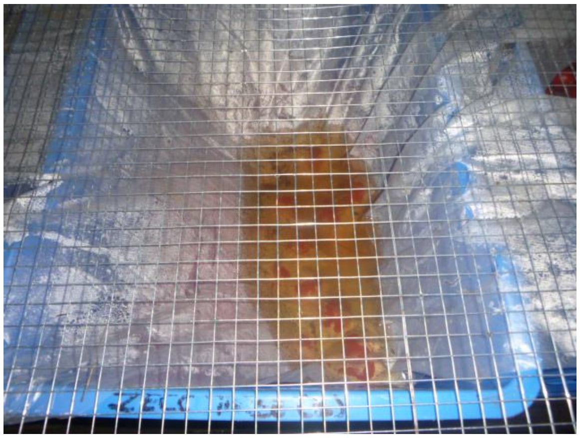


Fungi found in the ZECC in Honduras research trials undertaken during rainy weather (Trial 1)

Results after one week of storage in the ZECC vs Ambient air in Tamale, Ghana (April 2014)

Trial	Temperature and RH%	Weight loss	Maturity	Visual Quality
1	28-45° C; 35-95% RH	More than 60% weight loss in ZECC (rats ate the tomatoes); 30% weight loss in Ambient	100% red in both	Extremely poor in ZECC due to rat damage; fair to poor in Ambient air
2	25-48° C; 35-100% RH	3% weight loss in ZECC; 25% weight loss for Ambient	100% red in both	Some mold on tomatoes, but otherwise Good quality (very firm and fresh) in ZECC; Ambient less firm, less fresh.
3	Very high RH% in both; heavy rains during trial	Weight gain in ZECC; 20% weight loss for Ambient	100% red in both	Mold on both, similar quality range in both (good to extremely poor)

Trial #3 in Ghana: ZECC visual quality (good when not moldy) vs Ambient (good to extremely poor). Notice the low volume of tomatoes used for the trial – costs and availability limited the usable amount researchers could find to purchase in the market.



Rain water collected on plastic sheeting of ZECC in Ghana

Rat in ZECC experimental plastic crate in Tamale, Ghana (Trial #1 -- the subsequent trial incorporated a rat proof wire screen mesh)

Solar dryer comparison studies:
For the solar drying studies, the timing for stopping the trials was based on a target of 10% moisture, or approximately 17% of the initial weight of the samples of chili peppers. For a 130g sample, this was a target weight of 22g. The tare weight of the sample trays averaged 45g in Honduras, so the total target weight of the sample + tray = 67g. (PI note: We started referring to these as sample “baskets” because people were getting confused with the wooden Trays that we used for the BIG dryer trials…whatever it takes to help reduce confusion and support clarity, calm and confidence!)

Results of UCD solar chimney dryer vs traditional indirect cabinet dryer in Honduras (March-May 2014)

Trial	Temperatures in solar dryers	Drying time to 10% moisture (hours)	Visual Quality	Comments
1	March Mostly cool temperatures Range: 14-34°C Max = 50°C in both UCD and Cabinet dryers	46 hours for UCD Chimney dryer; 75 hours for Cabinet dryer	Good for UCD Chimney dryer; fair for Cabinet dryer	Misunderstanding of the stopping target sample weights carried drying trial into Day 8.
2	April Range: 15-52°C Max = 52°C for UCD; 45°C for cabinet dryer	55 hours for UCD Chimney dryer; 80 hours for Cabinet dryer	Fair for both	Huge day/night temperature swings
3	May Range: 17-50°C Max = 50°C for UCD; 41°C for cabinet dryer	58 hours for UCD Chimney dryer; 126 hours for Cabinet dryer	Fair to good for UCD Chimney dryer; Good for Cabinet dryer	Huge day/night temperature swings UCD chimney dryer samples had some discoloration (got too hot?)

Results of UCD solar chimney dryer vs traditional indirect cabinet dryer in Ghana (April 2014)

Trial	Temperatures in solar dryers	Drying time to 10% moisture (hours)	Visual Quality	Comments
1	Range: 35-50°C Max = 53°C for UCD; 45°C for cabinet dryer	25 hours for UCD 47 hours for Cabinet	Excellent for both	

Loaded trays of the UCD solar chimney dryer in Ghana

 Loaded trays of the cabinet dryer in Ghana

Example of tray labelling for experiments

Smoke tests conducted on the solar dryers:

Country	UCD solar chimney dryer	Traditional solar cabinet dryer	Comments
Tanzania	18 seconds 22 seconds	The research focus was only for the UCD prototype…	Rainy weather, used a "smudge stick"
Ghana	7 sec @ 7:30 am cool morning (ambient Temp 27C)	No data	Many tries for the Cabinet dryer but could not see any smoke. We surmise that

Country	UCD solar chimney dryer	Traditional solar cabinet dryer	Comments
	17 sec @ 2pm (ambient Temp 40-45C.)		ambient temp was just too hot! 40-45°C at noon (we took it then because we wanted to know the velocity when the heated air thru the UCD direct table area was fastest) but the air was "shimmering" when we looked for smoke…hence we tried in the cooler early morning.
Honduras	6 sec	17 sec	conducted on trial # 1 only (when PI was there to support)

Notes: finding appropriate materials for conducting smoke tests was very difficult for the PI and the teams in all the sites. Even finding working matches was difficult in the rainy weather We will need to find a better method for conducting these tests for the Nov-Feb trials.

Report from Ghana team:
Smoke test was carried out on April 11, 2014 at 7:35am, (27C outside air). The time taken for smoke from the entrance to exit through the UCD chimney was 7 seconds and on April 16, at 1: 53 pm, the time taken for smoke to exit the UCD was 17 seconds. We discussed and thought this was because the outside air temperature was too high (40-45C) and we could not see the smoke very well. We even went up on a ladder to the top of the UCD chimney to see it better. We tried the smoke test many times with the Cabinet, as a Team, but we could not see it.
This test was carried out to determine the speed of the air over and past the drying chilies. The faster the air flow the faster the chilies would dry as the faster moving air would remove the water from the chilies.

Capturing the details

When we first began discussing these studies with the Horticulture Innovation Lab ME team, it was late in 2013, and the weather was suitable for comparing evaporative cooling and solar drying technologies at the 7 sites. By the time the RFP was issued, and the project was funded in March 2014, the dry season had passed in most of the sites, and the rainy season had begun.

The designs for the ZECC and traditional solar cabinet dryer have been well established and field tested, while the design for the UCD solar chimney dryer was still "under development". The PI iterated many times with the designers, asking about the details on past prototypes, discussing options for materials, and finalizing the dimensions, materials, siting and management issues. The prototype built for this project in Tanzania was intended to provide the PI with the opportunity to work out the bugs, determine the final dimensions and develop the final materials list and construction instructions that would be used by the teams in Honduras, Ghana, Guatemala and Thailand. In reality, each team's site had issues that prevented the "ideal" prototype being constructed on their site—for example, for each site different local materials were available, site restrictions (size, security, shading, etc.), different local carpentry approaches (mindset) methods and tools (and sometimes electricity) were commonly used, and different irrigation systems for the ZECC were available.

The main problems the teams faced can be categorized into four areas: weather issues, produce issues, technology issues and management issues.

Generally, across all the sites, there was unpredictable weather, high prices and difficulty in obtaining good quality produce, and many technical, construction and management issues to deal with. In Chiang Mai they would like to use a more traditional hot chile as this would be a better demonstration and one that the local peoples might be more apt to embrace. In Guatemala City they would like to use the traditional smaller tomato and not the hothouse tomato (we only used the hothouse because we could not find quality tomatoes in the market), and in Sololá the university has their own greenhouses and produce their own tomatoes.

ZECC set-up and experimental studies

Timeline	Country/site	Weather issues (unusual temperatures, rain, wind, etc)	Produce issues (availability, quality, consistency, etc)	Technical issues	ZECC Management issues
General, across all sites		Unpredictable weather conditions	Higher priced produce, lack of availability once the rainy season started Difficult to obtain produce early in the morning when it is cooler weather – teams often did not start work until later in the day Teams lack confidence in buying from local wholesale markets and from farmers (need more practice and capacity building) Produce is sold by heaps, piles,	Some teams wanted to put the ZECC indoors (for security, protection from pests)	Needed to pay more attention to the saturation of the bricks/sand, often let ZECC dry out between waterings

Timeline	Country/site	Weather issues (unusual temperatures, rain, wind, etc)	Produce issues (availability, quality, consistency, etc)	Technical issues	ZECC Management issues
			bowls, etc, and not by weight. Difficult to communicate with market ladies on needed quantities, quality For the trials, should the calyxes be left on (less water loss) or taken off (less puncture damage)?		
April	Ghana	Rain starts in April	Lack of okra (our first choice for the studies), very high priced tomatoes (over-ripe)	Clay bricks melted	Rats in the ZECC (eeek)!
May	Guatemala	Hurricane season starts in May (record), very windy, driving rains			Fungal growth in the ZECC Security issues kept the site closed on weekends
May	Bangkok	High winds, rain			Mold in the ZECC

Solar Drying technology set-up and experimental studies

Timeline	Country/site	Weather issues	Produce issues	Technical issues	Solar dryer Management issues
General, across all sites		Unpredictable weather conditions	Higher priced produce, lack of availability once the rainy season started Trays needed full loads for accurate results, so each trial was very	None of the teams were familiar with solar driers, needed the carpenters to work directly with LEW Termites were a problem in	A lot of management is required for maintenance of the driers, keeping the plastic clean and free of tears, protecting the dryers during bad weather.

Timeline	Country/site	Weather issues	Produce issues	Technical issues	Solar dryer Management issues
			expensive (requiring $6m^2$ of produce). Difficult to obtain produce early in the morning when it is cooler weather – teams often did not start work until later in the day Teams lack confidence in buying from local wholesale markets and from farmers (need more practice and capacity building) Produce is sold by heaps, piles, bowls, etc, and not by weight. Difficult to communicate with market ladies on needed quantities, quality No one liked to chop chilies, even with gloves.	all sites, need to use some kind of barrier or insecticide on legs of dryers Plastic sheeting needs to be "weighed down" in 3 places. Use of rocks can tear the plastic. Use of bamboo pole to roll the sheet when opening the cover works, but the pole must be very long and straight. Needs 2 people to roll the cover open and closed. Insects enter the UCD dryer unless a net barrier is placed across the opening and at the top of the chimney. Splinters from wood trays and the long "baton" that hold up the plastic cover above trays = food safety issue.	Need to find a place to store these dryers during the rainy season. Some teams wanted to have them taken apart and reconstructed each year—a huge expense. Rain puddled up on the UCD chimney dryer cover during rains, needed to be carefully drained off to avoid wetting the produce inside the dryer Rains leaked down into the chimney Changing the dimensions of the table height to match local plastic sheeting widths and local heights of workers would be beneficial Huge size of UCD trays made lifting, carrying and handling difficult for the workers. Often took 2 people to load one full tray. Repairs and maintenance require a staple gun (LEW provided one to attach netting to trays) – but how will teams get more

Timeline	Country/site	Weather issues	Produce issues	Technical issues	Solar dryer Management issues
				Local netting/mesh used for trays was not likely to be food safe, if thin would sag, needed extra support. Smoke test was very difficult, bee keeping (and poofers) are not widely known. Used wet and dried grasses… difficult to see the smoke.	staples when they run out? A huge amount of labor is required for just a few hours for preparing and loading the dryers – this can be a problem in some sites.
March	Honduras			Power tools used by the carpenters required a 300m cord to reach the electric plug Bee poofer melted the plastic sheeting	
April	Honduras			Carpenters wanted to use pesticides treated wood (for termites contained Arsenic: not food safe!) because the lumberyard sold only this this type in already dimensioned	

Timeline	Country/site	Weather issues	Produce issues	Technical issues	Solar dryer Management issues
				wood. Easier and cheaper for carpenter and project.	
March	Tanzania			No nails used, carpenters dovetailed all the corners—tray construction took a long time.	
April	Ghana	High winds, rain starts very early		Smoke test was difficult (too hot to see the smoke! 40- 45C ambient at noon!))	Plastic cover ripped, chimney pipe/boot connection leaks Chimney required strong "guy wires" to stay upright
May	Guatemala	Hurricane season starts in May (record) – very windy driving rains		Shorter statue of local people found it difficult to reach the trays of the dryers. Will try a plastic "sandbag" made into a long heavy roll to hold down the plastic sheeting.	Wind, rain damage, conditions not possible for solar drying
May	Bangkok	High winds, rain			

Appendix D is a complete set of "Capturing the details" tables on the lessons learned for each country and each technology (more than 100 pages of the PI's notes).

A few photos of the constraints faced by the research teams:

Finding the correct type and size of bricks for the ZECC (Chiang Mai, Thailand)

Finding and storing sufficient water for the ZECC (Tamale, Ghana)

Only a very small space was available for building the 3 technologies and weather station at Universidad del Valle, Guatemala City

Sloped site being filled and leveled in Chiang Mai in June, but already slumping and cracking in July, causing ZECC to lean and have shorter lifespan.

The tiny size of the bricks available in Bangkok, Thailand made ZECC construction costly and time consuming (over 5000 bricks were used: brick size: 13.5cm x 6.0 cm x 3.0 cm)


Finding good quality tomatoes in Ghana (most were bruised and over-ripe, sold in enormous boxes) above, left; teaching the market women about maturity, quality and shelf life (above, right). At this season the tomatoes needed to be trucked 8 hours from Burkina Faso. They would be harvested red ripe and transported in the large wooden crates in open trucks.

Finding the correct wood for the dryers Tamale, Ghana)


Wrestling with the large piece of clear plastic sheeting on the UCD chimney dryer (Zamorano, Honduras)

 Sololá, Guatemala

The standardized size of the UCD chimney dryer (1 meter high tables and $1m^2$ trays) was found to be too big for some of the teams and their local helpers to easily handle the trays and use the dryer. They suggested the Table for future studies to be 70 cm high as did the teams in Thailand.

Heavy rain collected on the plastic sheeting of the UCD chimney dryer and had to be carefully removed in order to avoid damaging the plastic and the drying products. This caused the plastic to stick to the drying produce, and when removing the water often the drying produce was moved and “bunched together’ so that appropriate drying protocol (the produce pieces separated from each other on the tray) was disturbed.

Costs for the technologies

The costs for materials and construction of the three technologies at each site is provided in the following table. The average cost for the ZECC (bricks/sand, cover, shade and irrigation) was $725, which was about 17% higher than budgeted. Costs were higher than expected due to several major issues: the first ZECC constructed in Ghana "melted" during our initial waterings to saturate the bricks and sand, so custom made concrete blocks had to be used to construct the second version, and the bricks available in Bangkok Thailand were so tiny, 13.5cm x 6.0 cm x 3.0 cm) that more than 5000 had to be used to construct the ZECC. The Chiang Mai TEAM location was 3.5 hours from the city (Chiang Mai) and the appropriate bricks had to be transported from Chiang Mai. The shade structures costs varied greatly depending on the material costs, availability, transport costs and labour costs in Bangkok and Chiang Mai. The cost of the shade structure and the plastic crates, the cost to transport the bricks and sand, the cost in Chiang Mai to prepare the site (they had to bring in fill dirt and shore it up (not to be advised!) were all higher than in Bangkok.

The average costs for the two different types of solar dryers was similar ($541 for the chimney dryer and $528 for the solar cabinet dryer) and both cost about 30% more than budgeted. The UCD solar chimney dryer can hold twice as much product as the traditional cabinet dryer in each batch, and therefore costs half as much if the cost is calculated per kg of product.

Technology costs (including materials, transport and construction labor) for the 7 sites

	Technologies					
Sites	**ZECC**	**Shade Structure**	**ZECC Irrigation**	**UCD Solar Chimney Dryer**	**Solar Cabinet Dryer**	Notes
Ghana, Tamale	$280.00 clay $339.38 cement	$96.52	$389.41	$708.05	$418.93	Had to build two ZECCs Clay bricks cost 17¢ each, cement blocks cost 26¢ each
Guatemala City	$362.07	$267.75	$29.05	$713.53	$635.32	
Guatemala, Solola	$424.55	$294.24	$121.88	$713.53	$635.32	
Honduras Zamorano	$307.50	$0.00	$17.76 brought from USA by PI	$603.75	$462.57	
Thailand Bangkok	$469.13	$297.42	Used materials already owned	$531.85	$494.89	
Thailand Chiang Mai	$615.55	$160.32	17.76 UCD (brought	$521.03	$523.00	

	Technologies					
Sites	**ZECC**	**Shade Structure**	**ZECC Irrigation**	**UCD Solar Chimney Dryer**	**Solar Cabinet Dryer**	Notes
			from USA by PI) Drip tape plumbed into nearby water faucet source			
Tanzania, Arusha	N/1A	N/A	N/A	$834.19	N/A	12 trays (prototype)
total	$2,798.18	$1,116.25	$558.10	$3,791.71	$3,170.02	
average	$400.00	$186.04	$139.53	$541.67	$528.34	

Unit costs for the individual items can vary widely, even within one country, and often there is a minimum number of units or weight that must be purchased for a factory to consider making a custom product.

A good example of this comes from the prototype in Tanzania, where the cost of lumber was very high and choice of materials and carpentry supplies was limited.

Costs for UCD Dryer in Arusha Tanzania			
	item	US$	Comments
Lumber	3x2 RFT (360 x 150)	213.00	wet and difficult to find, need to cut from large planks
	10 x 1 RFT (90 x 25000)	140.00	electricity went out first 3 days and could not cut
	2hrs Machine	50.00	difficult to find carpenters
	Nails	4.70	
	screw 1 box	1.60	
	Glue	3.10	
	transport of materials to AVRDC	18.60	
	MDF, 1 piece (med. Density fiberboard	49.70	only needed one half of a piece but had to purchase the entire sheet
total wood / materials for carpenters		479.50	
total work for carpenters		198.80	
Total		$678.30	

Two more examples come from Anloga, where Sena Ahiabor gathered information on local costs for the materials to build ZECCs and solar driers. From his written report:

1. The perforated plastic basket is being manufactured still. They have the mold but I was told they cannot take a small order although they have just about 50 pieces of what they

have constructed left to be sold. The cost of one is GH C 17.00 Factory price with pre VAT. They thought I was ready to buy them and I told them I am not ready yet and they made it known to me that it takes two days for them to mount the mold and can only produce about 2000 pieces minimum to a customer. They said if I am lucky and there is an order, then I will be lucky else I will have to buy it now when they have some limited stock left.

2. I also got the prices for plastic sheets both clear through and the black types from a factory in Accra. The width is 72" or 1.8m. They only come in rolls doubly folded. They come with a minimum roll of 46.35kg and sells as GHC 6.800/kg for the black sheet and 50kg for GHC 7.40/kg for the clear through type ex-factory.

In addition, there were costs associated with conducting the research trials. Small costs (using ATMs to get cash, getting local transport to go to a market, buying a missing tool, hiring laborers to move sand or bricks, wire transfer fees to send funds to the teams from WFLO, etc.) added up over time. The cost for fresh produce increased greatly when the sites were far away from the farms or wholesale markets (Tamale, Sololá, Chiang Mai). In some sites, labor had to be hired to pre-sort tomatoes or to pre-sort, clean and chop the chilies (in Sololá we hired the women and in Chiang Mai we hired local women and the staff). Most of the teams provided their own labor for data collection as an in-kind contribution to the project, but at times had to hire assistance, for example to check and water the ZECC on weekends when the university campuses or research centers were closed. Also, the staff was paid extra and overtime when it was required for them to administer the experiments during non-work hours.

Theoretical Cost/Benefit Comparisons for the two Solar Dryers
The following table provides an example of how the UCD solar chimney dryer, while initially costing more to construct, can offer a better return on investment since it can dry more produce in a shorter period of time.

Assume purchase and process chilies to dry product during one week in Guatemala

	Traditional indirect solar cabinet dryer 2m^2	UCD solar chimney dryer 4m^2
COSTS		
Solar dryer construction	$600	$700
Produce @ $0.50 per kg	$25	$50
Labor for cleaning and preparations	$20	$40
Packaging	$10	$20
Sub-total cost of produce, labor and packaging	$55	$110
EXPECTED BENEFITS		
% losses	5%	5%
Drying time for 100 kg	2 weeks	1 week
Amount produced for sale in 1 week	47.5 kg dries to 8.1 kg	95 kg dries to 16 kg
Value/kg	$10	$10
Total market value	$81	$160

	Traditional indirect solar cabinet dryer 2m^2	UCD solar chimney dryer 4m^2
Market value – costs for produce, labor and packaging = potential weekly profit	$81 - $55 = $26	$160 – 110 = $50
Relative profit per week		**+$24**
Time required to pay for solar dryer (ROI)	$600 / $26 = 23 weeks	$700 / $50 = 14 weeks
Potential weekly profits after paying for cost of dryer	$26	$50

e. Roles of Partners

The following is list of the team members whose expertise is critical to each phase of the project and the role the partners who hosted the research project. The Horticulture Innovation Lab ME team and previous Horticulture Innovation Lab PIs provided contact information for lead team members, who in each country assisted with identifying carpenters and laborers for construction activities, graduate students and/or young faculty who want to participate in workshops and data collection.

A total of 144 people on 7 teams (67 men, 77 women) participated in the capacity building workshops and management of the technologies.

Prototype development: **Tanzania**
Radegunda Kessy, PTSC manager at AVRDC in Arusha
Dr. Ngoni Nenguwo, Postharvest Specialist, AVRDC
Hazinah, Omari, Taremo, Adams, Annete, and the other 7 other AVRDC supporters
Carpenter Christopher Maro, and assistant
Odette Ngulu, Bertha Mjawa, Laurence and Gaspar

Radegunda and Christopher

Taremo and AVRDC Support

Dr. Bertha Mjawa Hazinah

Fieldwork TEAMS (data collection):

Tamale, Ghana

Some of the outstanding Tamale, Ghana team

Dr. Flora Amagloh, Mr. Sena Ahiabor, Richard Atuna, Paul Azure, Eric Yuoni, Prince Sakyi, Moses Kakrabe, Dr. Francis Kweku Amagloh, Isaac Boaresa, Yussuf Abubakari, Ibrahim Fusena, Dr. Joyce Bediako, Carpenter James and assistant, Chef Natse and Hamdina, 5 local farmers

Anloga, Ghana (representing this region)

-- Mr. Sena Daniel Yao Ahiabor, Agronomist, CEO of Tip Top Foods LTD

Honduras – recommended by Dr. Julio Lopez

Tegus/Tegucigalpa - site of Zamorano Univ, Hort CRSP Regional Innovation Lab

Data collection in **Tegucigalpa**

Nidzy, Ivanna, Dr. Julio, Paty, Carmen

Dr. Julio Lopez, Ing Patricia Arce, Ing. Ivanna Vejarano Morena Nidzy Trujillo, Gabriella Carmen Valeria Pérez, Carpenter Marcos and assistants, The many, many (40 plus) students who so willingly gave their time and support!

Guatemala

Guatemala City -- -- recommended by Dr. Julio Lopez

Vilma, Edwin, Dr. Ana, Pat

Silvia, Lizanne Vilma

Jairo and Carpenter Assistants

Julio, Josue, Bryan

Dra. Nohemy, Edwin, Silvia

Dra. Ana Silvia de Ruiz, Universidad del Valle de Guatemala (UVG), Ing. Vilma Porres and Ing. Silvia de León, Ing. Patricia Palomo, and all of her 18 students who helped prepare the chilis. Kelly Mishell León, Joaquin Flores, Nohemy Zelada de Perez, Carpenter Jairo Reyes and his assistants

Sololа -- UVG, *Rural Training Campus* at Sololá:
Ing. Edwin De León', Ing Josue Ajcalon, 5 '4th year students', Josué Bocel, Ing. Sofía Gómez, Dr. Antonio Orellana, Ing Jaime Roquel, Dr. Armando Cutz, 4 Maintenance personnel, 7 local women, and all that helped in ZECC construction

Ing Josue and local Ladies TEAM Ing. Edwin

Thailand – recommended by Dr. Poon Kasemap, Director Horticulture Innovation Lab Regional Center of Innovation, Kasetsart University

Bangkok –Kasetsart Univ, Horticulture Innovation Lab Regional Innovation Lab Research and Development TEAM members: Dr. Jate Sathornkich
Miss Chompunut Chayawat, Miss Ornuma Duangngam, Miss Samorn Nachainat, Miss Dokkeaw Chura, Miss Trachin Lomsrisakul, Miss Rungtawan Rhabkhum, Phetrada Kayankit, Sukanya Char, Mr. Aidil Azhar

Dr. Jate, Aidil, Champunut, Ornuma Samorn, Dr. Jate, Ornuma, Dokkeaw

Chiang Mai –
Mr. Abram Bicksler, Director ECHO Asia Impact Center
Team: ECHO Impact Center /Chiang Mai

Rebecca Garofano Office Manager
Zachary S. Price, Technical Advisor,

“Toh” BoonsongThansrithong, Agriculture Operations Manager
Courtney Huggins
Patrick Desmond Fitzsimons

Team: ECHO Asia Seed Bank/ Fang/Mae Ai
“Wah” Ratakarn Arttawuttikun Seed Bank Manager
“Paw” Yuwadee DanmalidoInformation and Quality Control Technician
Sang, Erth, Chai, Brad, Momo and EQ, 6 “Girls), and support from the staff at UHDP
Thank you to Dr. Jate Sathornkich for his week of assistance!

Abram, Zach, Toh, Pat, Lizanne, Courney, Jate

Wah and “Girls” Paw, Zach, Abram, Toh, Chia, Erth, Sang, Wah, Courtney

Technical support (WFLO and PEF)
WFLO’s Senior Technical Advisor for Horticulture and Food Security, Lisa Kitinoja assisted with proposal development and provided technical assistance with research design and implementation of the studies. She is the lead author for preliminary and final reporting. Dr. Kitinoja was Co-PI for WFLO on Barrett’s Horticulture CRSP pilot project in East Africa, and technical advisor/postharvest consultant for the comprehensive projects led by Kate Scow (Uganda) and Jim Simon (Zambia).

Dr. Pat Brown, member of the board of directors of The Postharvest Education Foundation (PEF) provided voluntary technical assistance and logistical support for the PI during site visits in Honduras, Guatemala and Thailand. The value of the combined volunteer time of Lisa, Pat and Lizanne (beyond any paid time allocated in the budget) was nearly $30,000.

f. Timeline of Activities

The original timeline to accomplish the planned project activities and expected outcomes fell within a 6 month time period, beginning with project preparations and start-up in February-March 2014.

All the technologies were successfully set up in 6 research sites, but data collection was greatly limited by poor weather, so the final data in 5 sites will be collected by the trained local teams during the period of November 2014 through February 2015. This preliminary report will be provided to the Horticulture Innovation Lab ME in August 2014, and the final project report will be submitted by WFLO in March 2015. No additional funds will be required, and all the teams are ready to move as soon as the rainy weather clears. Technical assistance will be provided for the teams as needed on a voluntary basis via The Postharvest Education Foundation (specifically by Lisa Kitinoja, Lizanne Wheeler and Pat Brown).

<table>
<tr><td>Training and set-up</td><td colspan="5">Data collection locations 2014 (PI Traveled to 7 sites)</td><td>2015</td></tr>
<tr><td>February</td><td>March</td><td>April</td><td>May</td><td>June</td><td>July</td><td>Nov-Feb</td></tr>
<tr><td rowspan="4">Tanzania prototype</td><td rowspan="4">Construction of technologies and Workshops for all cooperators

Honduras- March</td><td></td><td>Solola</td><td></td><td rowspan="4">Chiang Mai

Data compilation and Preliminary Final Reporting</td><td rowspan="4">Solola

Guatemala City

Tamale

Bangkok

Chiang Mai</td></tr>
<tr><td>Tamale (Anloga)</td><td>Guatemala City</td><td>Bangkok</td></tr>
<tr><td></td><td>Tegucigalpa (completed)</td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

g. Outreach and Capacity Building

A wide range of outreach activities were undertaken to directly build research capacity.

- Working directly with collaborators in research activities via hands-on training in technology design and utilization was undertaken and completed in 5 countries.
- Final report results will be used by the Horticulture Innovation Lab team to develop extension materials suitable for local dissemination via the Horticulture Innovation Lab Regional offices.
- Recommendations will be disseminated and promoted via the Global Horticulture Knowledge Bank (http://hortkb.weebly.com/).

Postharvest Capacity Building Workshops and Hands-on Activities led by Lizanne Wheeler during her site visits

Research Site Total person days of training	**Dates /Number of days of training**	**# of Men**	**# of Women**	**# of Students**
Arusha, Tanzania 102	February 10-12, 28, March 3-6 / 8 days	56	46	0
Tamale, Ghana 275	April 1-11 / 9 days	240	35	160
Honduras 234	February 10, March 10 – 29 / 14 days	113	121	93
Guatemala City 455	April 21, 23, 25 and May 1-16 / 12 days	148	307	327
Solola 205	May 17 -31 10 days	129	76	126
Chiang Mai 143	June 14-30, July 2-4 / 15 days	70	73	0
Bangkok, Thailand 62	June 10- 15, July 7 / 5 days	22	40	19
Total 1476	73 days of training	778 men	698 women	

See Appendix E for a full list of topics and training events led by LEW (many of the 73 days included 4 or 5 different training activities and topics, each with a different group of people).

Appendix B contains samples of the many reports, Powerpoint presentations and capacity building activities the members of the 7 teams contributed to the project.

A capacity building workshop at SARI in Tamale, Ghana

A capacity building workshop on ZECC construction at Zamorano University in Honduras


A capacity building workshop on solar drying technologies in Guatemala City

Postharvest Capacity Building Activities provided locally by each project team (if any) after departure of PI

TEAM	Number of days of training	Men	Women	Admin, elders, leaders
Honduras (Zamorano)	March 19 1 day	67	46	113
	June 2-5 4 days	15	29	44
	June 12, July 1-3 4 days	12	4	12
	August 11-15 planned			

Note: the other teams will report in during August-September

The total number of people trained by the PI during 73 days of training events provided by this project was 1476, including 698 women, 778 men, of which 725 were students.

The total number of additional local people trained in postharvest handling, storage and drying technologies by the team in Zamorano, Honduras who had been trained by Lizanne Wheeler in the construction, use and maintenance of the technologies to date is 173, which includes 79 women, 94 men, 169 of whom were project leaders, administrators or elders.

On-going support for the teams is being provided by the PI via DROPBOX

Description of “Dropbox” support files for each TEAM: (Each TEAM had a separate Dropbox). This was created with each TEAM in advance of the PI’s visit to:

- To support the understanding and preparation of the project
- Allow an easy method for communication between the TEAM and the PI, as photos, designs, Youtube videos, documents were included in back and forth communication
- Set up and ‘easy to find’ and solid pathway:
  - For the PI to place:
    - project support documents needed for better understanding of the project needs (basic PH docs) (often customized for the particular TEAM)
    - Docs needed for the TEAM to carry out the experiments (ie. Colour charts, Visual Quality standards, etc.)
    - A place for the PI to continue to support the TEAMS learning (and training of trainers) by adding other references, websites, docs: before during and after the PI site visit
- for the TEAMs to send the Project information to the PI as was this was a “safe, backed up space”: (completed trial datasheets, hobo dataloggers download data, weather station data downloads, project photos, questions, etc.
- A Dropbox is free, and can accommodate many TEAM members (often there was a “confidential” Dropbox between the Official leads, the Leads on the ground, and the TEAM as a whole

This Dropbox method worked fantastically…and now it is difficult to “wean” the TEAMs off this Dropbox and create independence within their own TEAMS!

A sample list of the various items in a TEAM Dropbox:

- File on Solar Dryer Experiment (containing datasheet templates, completed datasheets and photos, trial photo label template, Methodology of experiment, location of experiment data collection sample baskets on dryer trays, list of materials and set up prep for conducting experiment/trials, hobo datalogger locations, etc)
- File on ZECC vs Ambient Storage Trials
- File on UCD and Cabinet dryer technical information (designs, materials, etc)
- File on ZECC technical information (design and material list of ZECC, site requirement needed, history (acknowledging Dr. Roy) of ZECC and photos, photos of plastic crates and dimensions (to help them in their search for the crate to be used), photos and descriptions on the bricks and sand to be used, template of material list, with costs and substitutes and comments for TEAM to complete, etc)
- File on ZECC vs Ambient Air Storage Experiment information (datasheet templates, completed datasheets and photos, trial photo label template, Methodology of experiment,

list of materials and set up prep for conducting experiment/trials, hobo dataloggers locations, etc)

- HOBO DATA Download file (where all weather station data and experiment download data should be placed so PI can access)
- Diagram of datalogger positions in experiments
- Datalogger locations, Serial numbers, for each expt and trials (noting the trial start and finish date and time) so actual trial data could be matched with the download
- Capacity Building documents (to be used during expts and to use in future Train the Trainer capacity building) the TEAMs often wanted more…so the PI gave them websites (UCDAVIS and PEF, and others so they would research on their own and get independence from the PI). A sampling of these docs are: Color Indices charts (not only for the tomatoes! But often for the produce that each TEAM was familiar with), Quality Rating Scales, Psychrometric chart and "how to use it" (as the PI taught all the TEAMS how to use the Pocket thermometer to get both the dry and wet bulb and then to use the psychrometric chart to chart the %RH …they really liked this! And helped them to start using and understanding the importance of Temp and %RH in their PH practices!!)
- Coolbot information all of the TEAMs were progressive and most of their institutions had cool rooms that were not working for various reasons…
- A simple chart (made by Dr. Lisa Kitinoja) of the comparison of different materials for insulation (the PI gave a discussion on understanding R-Value and gave samples of the double bubble reflectix)
- Information on the UC Davis annual PH workshop and the PEF e-learning and workshop opportunities
- Photos of other TEAMS technologies
- Other capacity building support requested specifically by the TEAMS

Recommendations

There are many researchable questions to be considered for future studies on the ZECC and UCD solar chimney dryer, some requiring the research team to have more than one of the same technology. We recommend that some of these teams be provided with funds for construction of a second ZECC and/or UCD solar chimney dryer, in order to test side-by-side, parameters such as dimensions, local materials, length, height, chimney size, plastic sheeting types, covers, pest management, etc.

Future research projects be undertaken in these 7 sites in Tanzania, Honduras, Ghana, Guatemala and Thailand since these teams have successfully been able to gain capacity in the construction and utilization of these postharvest technologies. In Sololá a prior project (Food for Progress, managed by TAMU under a USDA grant during the mid 2000s) provided a fully stocked postharvest/food processing facility, which is currently underutilized. The cost of electricity limits the use of the cold room, and the other equipment is largely not being used.

For those planning future projects, support will be required in terms of providing funds for supplies, labor, produce, transport, repairs/maintenance of the technologies and tools/equipment (such as digital cameras). Estimates for repairs of the plastic sheeting for the solar dryers (requiring new plastic, tape, etc.) are in the hundreds of dollars per year.

Deliverables:
1) Fully developed plans for the technology designs, materials lists, instructions for construction (included in this preliminary report)
2) Workshop report on training activities with collaborators (included in this preliminary report)
3) Package of raw data collected during the cooling and drying studies (organized as requested by the Horticulture Innovation Lab M&E team). See Appendix C for preliminary data, final data will be submitted in March 2015)
4) Preliminary report on technology design, set-up and capacity building (this report, prepared at the end of July 2014)
5) Financial report (to be submitted by WFLO in August 2014)
6) Final Report on project implementation, outputs, outcomes and indicators with recommendations for follow up studies (will be submitted in March 2015)

h. Sustainability

This is a stand-alone research project. Once the project is completed (data collected and research objectives met) the data will be compiled and the raw data delivered in a final report to the Hort CRSP ME for further analysis, dissemination and promotion via the Global Horticulture Knowledge Bank. (http://hortkb.weebly.com/).

The zero energy cool chamber, the two solar drying technologies and the weather station that have been constructed at each of the project sites will be available for long term use for future research, training and postharvest demonstrations.

i. Gender

Gender equity is central to achieving Horticulture Innovation Lab goals, and these simple postharvest technologies are designed to provide women with access to practices for extending the shelf life of their crops and methods for preserving perishable fruits and vegetables using low cost drying technologies. Project collaborators include both female and male research scientists and extension professionals.

Both in Guatemala and Thailand the height of the solar drying technologies was a real problem for the people, especially for the women. They requested 70cm instead of 1 meter high for the tables of the UC Solar chimney dryer and the cabinet dryer legs, but we felt we had to keep all the 6 teams' technologies standardized for this research project. The PI suggested that this would be an improved modification when they build and share the technology to others in their spheres of influences.

j. Innovative Technologies

The “disruptive” or innovative technologies or processes included in the proposed project include both the cooling and solar drying technologies under investigation. Their **low cost and ease of use** is central to their potential for impact, since when shown to be technically feasible they can be more easily adopted and managed by smallholders compared to other more expensive technologies.

k. Literature Cited

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l. Monitoring and Evaluation Plan

Items marked in RED are still to be completed during November 2014 through February 2015

Objective 1: To characterize the cooling performance of the ZECC compared to ambient air storage under varying RH/Temp climate conditions				
Activities	Outcomes	Measure of success	Documentation of success	Impact
Identify specific sites	8 sites (2 per zone) identified	Collaborators agree to participate	Signed agreements (March 2014)	Project can proceed as planned
Workshops planned	Training plans with designs, instructions, materials list	Documents completed	Written report	Plans available for future projects and dissemination
Workshops on ZECC and data collection methods	Workshops held in 7 sites	ZECC is completed	Photos, trip reports (March-May 2014)	7 ZECCS available for research and training purposes
Experiments are set up with collaborators/data is collected	Data is gathered and organized by collaborators	Data collection is completed	Reports on data collection and results (planned for May –July 2014) New date: March 2015	ZECC performance is fully characterized New date: March 2015

Objective 2: To characterize the drying performance of the UCD Chimney dryer and traditional indirect cabinet dryer under varying RH/Temp climate conditions				
Activities	Outcomes	Measure of success	Documentation of success	Impact
Identify specific sites	8 sites (2 per zone) identified	Collaborators agree to participate	Signed agreements (March 2014)	Project can proceed as planned
Set up a prototype of the completed design for the UCD chimney dryer	LEW constructs a solar dryer in Arusha (model to use for workshop development)	UCD chimney dryer completed	Photos, written report (March 2014)	Plans available for future projects and dissemination
Activities	Outcomes	Measure of success	Documentation of success	Impact
Workshops planned	Training plans with designs,	Documents completed	Written report	Plans available for future projects and dissemination

	instructions, materials list			
Workshops on solar dryers and data collection methods	Workshops held in 7 sites	2 solar dyers per site completed	Photos, trip reports (March-July 2014)	14 solar dryers available for research and training purposes
Experiments are set up with collaborators/data is collected	Data is gathered and organized by collaborators	Data collection is completed	Reports on data collection and results (planned for May –July 2014) New date: March 2015	Solar dryers comparative performances are fully characterized New date: March 2015

m. Performance Indicators. (MS Excel sheet will be used for final reporting)

Seven Horticulture CRSP performance indicators, as described in the full table available online (http://hortcrsp.ucdavis.edu/main/forms_for_PI/Indicators_All.xlsx) will be used to track this 6 month long Focus Project.

Capacity Building for the 6 Teams:

Indicator	Fiscal Year 2014 (Projected)		ACTUAL
A159 Number of host country institutions, agencies and organizations in direct cooperation or collaboration	Postharvest	7	10
A164 Number of **workshops** conducted for host country institution, agency, and organization personnel	Postharvest	7	73
A169 Number of host country professionals **attending** workshops, training conferences, or similar – FEMALE	Postharvest	5	77
A174 Number of host country professionals **attending** workshops, training conferences, or similar – MALE	Postharvest	5	67
A224 Number of host country professionals **directly involved** in conducting Horticulture Innovation Lab **research activities** (FEMALE)	Postharvest	5	77
A229 Number of host country professionals **directly involved** in conducting Horticulture Innovation Lab **research activities** (MALE)	Postharvest	5	67
A234 Number of **research projects** of potential benefit to US hort industries	Postharvest	2	2

IV. Statement of Institutional Experience

Founded in 1943, The World Food Logistics Organization (WFLO) is a non-profit organization dedicated to the proper handling and storage of perishable products and the development of systems and best practices for the safe, efficient, and reliable movement of food to the people of the world. WFLO serves as the technical assistance arm of the Global Cold Chain Alliance, providing education and research services to companies concerned with producing, processing, shipping, transporting, and storing goods requiring temperature control.

Experience across the entire cold chain makes the WFLO uniquely qualified to draw upon technical, scientific, and human resources to conduct training, provide international technical assistance, and to produce educational materials and cold chain market analysis reports used to promote or attract investment into the perishable foods supply chain industry globally.

Over the last 5 years, WFLO has been on the cutting-edge of research related to postharvest loss reduction and technology identification/adoption. In 2009, WFLO implemented a 1.2 million dollar grant from the Bill and Melinda Gates Foundations designed to identify appropriate postharvest technologies in order to improve market access and incomes for small horticultural farmers in Sub-Saharan Africa and South Asia. The main objective of the grant was to link postharvest and marketing professionals from two major US institutions (the University of California and World Food Logistics Organization) with African and Indian institutions, assess the levels and types of postharvest losses for fruits and vegetable crops, then design and field test interventions that can best reduce losses and improve incomes for small farmers. During 2010 - 2014, WFLO has been working with UC Davis PIs and the Postharvest Education Foundation (PEF) on several USAID Horticulture CRSP funded postharvest follow-up projects, including a pilot postharvest training and services center in Tanzania which is promoting some of these interventions, and postharvest technology field trials in Uganda and Zambia. Given our expertise in managing large postharvest-related research programs, we believe that we have the technical know-how, personnel and experience to manage this investigation in close collaboration with the Hort Innovation Lab ME.

VI. Budget: **See attached excel spreadsheet**

VII: Budget Justification and Cost Sharing Narrative

WFLO PERSONNEL

Senior Personnel

1. PI, Lizanne Wheeler LOE = 4.88 calendar months
   Lead trainer and researcher
2. Senior Technical Advisor
   Lisa Kitinoja – LOE = 0.33 calendar months
   Dr. Kitinoja will provide technical support.

Support Personnel

1. WFLO Administration – Nikki Duncan LOE = 0.5 calendar months

   Cooperators (independent consultants) @ 0.30 calendar months for each team per round 8 replications of the studies (one round of studies in each of 7 sites; only the team in Tamale will conduct a 2nd round).

WFLO TRAVEL

1. **International Travel**
   The budget includes international and regional travel to/from all of the 7 project sites over a period of 4 months. All trips included in the budget are for lead PI, Lizanne Wheeler. The budget also includes one trip to Horticulture Innovation Lab annual meeting in Honduras (March 2014). All international travel was budgeted according to the following estimates:

TRAVEL AND PERDIEM- WFLO Postharvest Technologies HORT CRSP M&E Project				
	Cost/Unit	# of Units		Total
A. International Airfares				
Amsterdam - Honduras (Tegucigalpa)	3,000	1	Trips	$3,000
Honduras-Accra	2,500	1	Trips	$2,500
Honduras-Guatemala (Guatemala City)	400	2	Trips	$800
Guatemala City-Accra (Ghana)	2,300	1	Trips	$2,300
Accra (Ghana)-Bangkok (Thailand)	1,600	2	Trips	$3,200
B. Regional Airfares				
Bangkok-Chiang Mai (Thailand)	200	1	Trips	$200
C. Per Diem (Hotel + MI&E)				
Arusha, Tanzania	256	5	Days	$1,280
Guatemala City (Guatemala)	223	7	Days	$1,561
Sololá (Guatemala)	182	7	Days	$1,274
Tegucigalpa (Honduras)	264	7	Days	$1,848
Accra (Ghana)	331	2	Days	$662

Anloga (Ghana)	140	7	Days	$980
Tamale (Ghana)	140	7	Days	$980
Bangkok (Thailand)	249	7	Days	$1,743
Chiang Mai (Thailand)	212	7	Days	$1,484
D. Local Transportation				
1. Airport Transfers	60	14	Trips	$840
2. Car Rental with Driver	70	60	Days	$4,200
E. Travel Prep				
1. Visas	250	2	visas	$500
2. Traveler's Medical Insurance	5	120	Days	$600
3. Inoculations	200	2	Trips	$400
TOTAL TRAVEL AND PERDIEM				**$30,352**

Per diem rates based upon published USAID allowed hotel and MI&E rates.

WFLO MATERIALS AND SUPPLIES

Approx. Cost to build complete set of technologies at each location: $1400 + $200 for labor/transport

- **ZECC Complete: $600** sand and brick chamber, chamber cover, traditional shade structure, simple gravity fed water system (250 L tank, raised on concrete blocks with hose for sprinkling the chamber)
- **Indirect: $400** (cabinet dryer with solar collector)
- **UCD Chimney Dryer: $400** (table top version as opposed to the original soil berm design):
  - (JFT and M Reid stated in a Hort CRSP document that the 'soil berm' version of this dryer costs were $150, adding that cost would vary with the locations)
- **Laborers, carpenter and transport of materials to each site: $200**
- **Research Materials:** $23,100
  - Data loggers (T/RH) and probes, digital scale, portable mini-weather stations, digital cameras, pocket thermometers. 7 sites x $3,300 = $23,100

WFLO INDIRECT COSTS

The rate used is 20% of modified direct costs.

COST SHARING

WFLO's Cost sharing will consist of:

1) Short Term Technical assistance LOE (LK, P. Brown) = 11 days = **$6709 planned**
2) **Actual volunteer time by Pat, Lisa and Lizanne = 40 days = $24,396**

3) Unrecovered indirect costs – the difference between the 20% rate allowed by the Hort CRSP program and WFLO's audited indirect cost rate which is 23.9% = **$5,532.96**

Total cost share = **$12,242 planned**
Actual cost share = $29,929

In addition: An unknown but substantial portion of our host country collaborators time was provided by their institutions as a cost share. The amount of funds budgeted for their participation is small compared to the time they spent to participate in workshops, prepare experimental set-ups, monitor and complete the research studies.