Abstract

The CoolBot coolroom system is a single-purpose post-harvest cold storage technology that transforms a wall-mounted air conditioning unit into a small-scale refrigeration system. This ability to store crops in low temperatures can extend the shelf-life of perishable horticultural crops and mitigate the lost revenue resulting from post-harvest losses faced by farmers in developing countries such as Uganda, in which there presently is no cold supply chain and therefore suffers from post-harvest loses of up to 30% of horticultural harvest. By reducing the loss in marketable products, livelihoods of limited-resource farmers could be advanced. With this in mind, the immediate objective of this research project is to evaluate and assess the necessary pre-conditions and circumstances contributing to the economic feasibility of adopting the CoolBot Coolroom system. The project site is within the Arua District of Uganda, and the assessment utilizes geographically, economically, sociologically, and agro-ecologically data specific to this region to simulate thermal behavior of the coolroom in order to establish and evaluate the payback period of the system for five possible consumers in three scenarios, if powered by: photo voltaic panels, a gasoline generator, and an electricity grid. From this sensitivity analysis, the relative benefit of the CoolBot Coolroom system is examined for those consumer profiles, and the economic feasibility for each investigated.

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I. Problem Definition & Introduction

In Uganda, post-harvest losses are immense. In particular, about 25-30% of the horticultural harvest is typically lost due to post-harvest conditions before getting to consumers. Temperature management is key to reducing such losses, yet cool-chains facilitating the transportation, storage and sale of horticultural goods is virtually unknown in Uganda. Depending on the product, incorporating economically feasible cold storage into the horticultural value chain will reduce post-harvest losses for agricultural products by extending shelf-life from 1 week to as much as 3 months. Increased shelf-life has the potential to increase income and employment rates throughout the fresh fruit and vegetable value chain.

The "CoolBot system" has been designed as a single purpose system for cheap cold storage of fresh produce and agricultural goods (Store it Cold). The CoolBot is a device which allows a common wall-mounted air conditioning unit to run at sufficiently low temperatures in order to keep a single room cold enough to function as a coolroom. The system has been widely implemented in the United States, and is currently under evaluation for financial, environmental, technical, political and social feasibility for resource-poor farmers in developing nations.

Five small-scale farmers in Yabiavoko village, Ombokoro Parish in Manibe Sub-County, Arua district, Uganda agreed to work with an in-country partner, Reach Your Destiny Consult, to construct a trial CoolBot coolroom. Reach Your Destiny Consult, in collaboration with the Horticulture Collaborative Research Support Program at the University of California, Davis, approached D-lab at UC Davis in order to investigate the feasibility of implementing the CoolBot system in Uganda. While this system faces a significant up-front investment, suggestions to reduce the cost of this system include the use of local construction materials and economic utilization of hot air discharged from the air conditioning unit. If the hot air could be utilized for another income generating purpose, it may result in a more efficient system as well as provide for a reduced payback period, thus making this technology a viable investment for small-scale farmers in Uganda.

This paper provides the cost-benefit analysis of the CoolBot coolroom system currently in the process of installation at Yabiovako village, Uganda. While further study is needed to optimize the construction and placement of this system within the local market value chain, capturing the 95 se Fahrenheit air yet released from the ai could decrease the efficiency and increase the cost of the cooling system. Therefore, this paper focuses on the capital cost and net present value of the current, single-use CoolBot coolroom system in Uganda. Our background research of various sectors of Uganda have been included as

a literature review, and HOMER software utilized to model the components of a a CoolBot coolroom powered by three different systems: photo voltaic (PV) panels, a gasoline generator, and an electricity grid. The cost and benefit analysis of each system is followed by scenarios which place the current CoolBot system in Uganda (which utilizes PV panels) at various points within the market value chain for fresh horticultural product and other possible agricultural goods. Finally, recommendations are made for further consideration and study of this system.

II. Background: Agricultural Sectors & Literature Review

Introduction
Uganda's population is over 33 million, with an annual growth rate of 3.56%, making it the second-fastest growing country in the world (CIA Factbook). Uganda has the second-highest birth rate as well, and half of the population is under 15 years old (CIA Factbook). Over 80% of the population of Uganda is employed in agriculture (Grimaud, Sserunjogi, & Grillet, 2007), mostly in rural areas, and mostly as subsistence farmers.

About a third of the country, nearly 7 million hectares, is devoted to agriculture. 70% of this land is devoted to the production of food crops for local consumption. 44% of the Gross Domestic Product (GDP) in 1999 and 90% of all export revenue is attributed to agricultural products. However, the monetary value of subsistence agriculture exceeds that of market crops (Cyclopedia of nations, 2011), and provides more than half the income for the bottom 75% of the population (MFD&ED, 1996).

Small-scale subsistence farmers constituted the poorest 31% of the Ugandan population in 2005, and 40% of the rural population is impoverished. Poor inputs and inefficient technologies prevent farmers from increasing production, and financial services which may encourage small-scale enterprises are often absent or unattainable. However low income is most often cited as the major contributing factor towards the poverty of rural communities, who lack the means to transport agricultural products to more populated areas (Encyclopedia of the Nations, 2011).

Post harvest losses are immense in Uganda (25-30%) and are due, among other causes, to inadequate or non-existent refrigeration facilities for horticultural products (World Bank, 1993, 1996). Given these post harvest losses, it is evident that the welfare of many Ugandans could be increased by investments targeting horticultural post-harvest handling and storage technologies. Since most of the Ugandan population works in agriculture, development projects focused on this sector could have far-reaching implications on the general population. However, in order to best evaluate opportunities for development and technological improvements in agricultural sector, it is imperative to consider the agroecological, financial, social and technical context for agriculture in Uganda.

Furthermore, a post-harvest technology such as the CoolBot, which is currently targeting rural farmer families, should be analyzed in this context to ensure the likelihood of the adoption and long-term sustainability of such a venture.

Discussion

A. Agroecology of Uganda
The country of Uganda lies on the Equator, and experiences temperatures between 15° and 30° Celsius. Over two-thirds of the country lies between 1000-2500 meters above sea level, and receives regular precipitation. In terms of land availability, of the total 241,548 square-km that comprise the country over three-fourths is available for either cultivation or pasture-land (FAO Country Profile).

There are seven general agro-ecological regions into which the country can be divided, with each having a specific set of socioeconomic and environmental characteristics (FAO). One important distinction to make in regards to the regions under consideration for this project is the differential rainfall systems between the northern regions and the rest of the country. In the north, rainfall averages between 900 and 1300 millimeters annually and has one dry season and just one rainy season– a unimodal distribution. However, the rest of the country, such as the central region, experiences two rainy seasons and two dry seasons annually– or bimodal distribution (Basalirwa).

Although within this system, average rainfall is slightly higher, (1200-1500mm per year) the average temperature (25° C) is comparable in both the northern and central regions (CFSVA). The impact on farmers, given their geographical region, is the tendency for those in the north to cultivate drought-resistant crops that are more capable of withstanding a longer dry season. They are therefore more likely to favor the cultivation of annuals in the north for subsistence, rather than invest in the cultivation of riskier cash crops (CFSVA), which hinders their ability to move into commercial agriculture (Wortmann).

Although agricultural production varies by region, there are four main crops that are generally cultivated at the household-level. The most prevalent of these is maize, which has consistently been found to be the most widely produced crop in Greater Uganda. The other three crops vary by region, but include: cassava, sweet potatoes, sorghum, and kidney beans (CFSVA).

In the northern region of Uganda, maize and sorghum are typically the primary crops. Cassava and sweet potatoes are also cultivated, but their production is intentionally avoided in some sub-regions because of their vulnerability to theft from the field. Moreover, few households within the northern region were found to cultivate cash crops, such as: tea, coffee, tobacco, and sugarcane (CFSVA). This pattern of cultivation is similar in the central region as well, where cereals, such as maize are most widely cultivated. Within this region, roots and tubers are also extensively cultivated (CFSVA). However, the National Agricultural Research Organization of Uganda estimates a 20-25% post harvest loss for root and tubers, and a result of arthropod pests, micro flora, vertebrates, and man (NARO).

Traditionally, cash crops such as cotton, tobacco, tea and coffee were grown in both the North and South of the country, however the production of all but the last of these commodities

collapsed in the late 1970s. Other agricultural products were developed in an attempt to bolster exports and feed the country. These include primary food and crops such as cassava and sweet potatoes, plantains, millet and sorghum, maize, beans and groundnuts, as well as important cash crops such as coffee, cotton, tea, sugar, cocoa and tobacco (Library of Congress, 2011).Recently, horticultural crops such as cut flowers, vanilla, chilies and medicinal plants are being promoted as high-value , and potentially high-revenue, products with the potential to address widespread poverty within the farming community of Uganda. In 1998, vanilla production, for example, was already the third largest amongst all African nations (Cyclopedia of nations, 2011).

B. Financial State

Although the lifting of a moratorium on commercial banks ended in Uganda in 2007, very few banking services are available to resource-poor rural farmers today[6]. The Uganda Development Bank (UDB), a government-owned bank dating from 1972, aims to promote/finance key sectors of the Ugandan economy. While the UDB does provide Project Term Loans and Trade Financing , the bank is focused providing loans for projects which add value to agricultural products and increase their profitability within the context of international trade[7]. Commercial Banks, such as the Development Finance Company of Uganda, may have begun as development finance institutions, they remain out of range to the average poverty-stricken Ugandan farmer.

In response to the growing need of rural farmers for capital and basic inputs, the Uganda Commercial Bank introduced the Uganda rural farmer's scheme in the late 1980s. Small loans were to be provided directly to farmers, particularly to women, with an interest rate just below that of commercial banks, 32%. As it turned out, while women had a higher rate of loan approval and loan repayment to loan borrowed ratio, actual loan disbursement levels was overall lower than that of men[8]. This program established a model of micro-finance institutions that were integrated into the formal financial system, which paved the way for an explosion of micro-finance institutions (MFIs) in Uganda.

Providing financial services to resource-poor farmers has been embraced by Uganda as a path out of poverty. Whether this is actually the case remains to be seen, however since 1997, when the Ugandan Government established the Poverty Eradication Action Plan, the lack of financial services available to the rural poor has been seen as an inhibiting factor towards "facilitating the expansion of the rural economy through modernization of agriculture(Nannyonjo and Nsubuga, 2004. 7)." The development of MFIs has been identified as an important policy intervention towards the overall growth of the Ugandan economy, however costs are often higher for MFIs than for those of formal finance institutions, due to the increased difficulty of reaching distant clients. Therefore, the estimated 1400 active MFIs today mostly take the form of small community based organizations, which are "generally unaware of micro finance best practices, outside the micro finance information loop, focused on rural outreach but have minimum numbers of client (Nannyonjo and Nsubuga, 2004. 10-11)."

C. Social implications

One of the most important issues in the adoption of agricultural technologies is land tenure. If the proposed technology is a small, portable piece of equipment, land tenure may be of little

importance, but if the technology is a permanent structure or building, farmers may be reluctant to adopt the technology if they do not own their own land. Since colonization, Uganda has had a history of the privatization of land holdings (Bruce & Marquardt, 1998). However, due to policy changes in the 1970's, privatized land was nationalized and converted into long-term leaseholdings, resulting in the eviction of many smallholder farmers and turning them into occupants (Bruce & Marquardt; Deininger & Ali, 2008). In the late 1980's, the land was re-privatized, leaving it in the hands of former leaseholders to register their land (Bruce & Marquardt). As a result, many people failed to do so. The registry process was further complicated by the decentralized registry offices, making it difficult for those living in rural areas to access them (Bruce & Marquardt). As a result, many rural farmers do not officially hold the lease to their land.

Four land tenure systems were re-established in 1995: Mailo, Freehold, Leasehold, and most dominantly, Customary. Customary Tenure, as the name suggests, adjusts the rules of land ownership according to local customs and traditions. This method does not lend itself to record-keeping, which leads to problems such as environmental degradation in the case of communal farming systems (e-IWM, 2008).

Uganda has a few large-scale commercial farms and an estimated 2.5 million smallholdings. Traditionally, women, who provide over half the labor for agricultural systems, focus on food production instead of cash crops (Cyclopedia of nations, 2011). In addition to domestic responsibilities, women are expected to grow the food that feeds their family, the value of which is not captured in the official GDP of Uganda. Unfortunately, bureaucratic requirements such as high administration costs and ownership documents prevent many women from registering interests in their land[3]. Thus, land ownership is accessible almost solely to men.

D. Technical aspects
In industrialized countries, post-harvest refrigeration is usually achieved through cold rooms powered by vapor-compression cycle machines. Access to reliable and cheap grid electricity is the prerequisite for such systems to be effective and economically viable. In developing countries, especially in rural areas, access to the grid is often unavailable and when available, of poor quality and unreliable.

Common applications of cold storage in Africa involve conservation of expensive products for export such as flowers (EU, 2010) and perishable food products such as dairy or fish (Hammerle, Heimur, Maggar, Paik, & Valdivia, 2010). In Uganda, at this point in time, there is little cold chain infrastructure. A recent EU report found only five central cold storage facilities in the country and revealed that only 10% of exporters use refrigerated trucks (EU, 2010), a serious constraint to the export of high-value horticultural products. At the rural subsistence level, refrigeration is not currently used for agricultural products, due to the cost of the system and lack of access to electricity.

Few Ugandans have access to energy supplies such as electricity and petroleum products, and 94% of the total energy supply comes from biomass (wood, charcoal and agricultural waste)

(Uganda Investment Authority, 2002). Around 1% of the population provides itself with electricity using diesel and petrol generators, car batteries and solar PV systems. Electricity is consumed by the residential (55%), commercial (24%) and industrial (20%) sectors, as well as for street lighting (1%) (mbendi.com, 2002).

Only 5% of all households in Uganda have access to electricity, and this percentage drops to 2-3% for rural areas. However, 84% of the households are located in these areas. (Ministry of Water, 2001). This is one of the lowest rates in Africa (Eberhardt A, Clark A, Wamukonya N, & K, 2005). Many towns, especially in the North, which are far from hydroelectric power plants, are still without electrical power (mbendi.com, 2002). In 2003, the Ugandan government set the goal to increase rural electrification from 2% to 10% by 2012 (Uganda Investment Authority, 2002), but in 2010 the rates are still below 3% (Buchholz & Da Silva, 2010).

The Ugandan government, with the support of the World Bank, is currently promoting renewable energy capacity-building. Promising technologies include biomass (firewood, charcoal and crop residues), as well as photo-voltaic and other solar technologies for water heating, cooling and crop drying, since solar radiation is about 4-5 kWh/m2/day (Uganda Investment Authority, 2002).

The cost of grid electricity changed significantly in the last 5-6 years due to increased demand and reduction of hydroelectric supply. Buchholz and Da Silva (2010) recently discussed electricity cost from alternative technologies in Uganda. Electricity cost (at the production level) can vary between 0.05 $/kWh and 0.39 $/kWh. More significantly, producing electricity locally with a medium-large size solar array (42 kW and 20 years of expected life of the system) costs 0.19 $/kWh.

E. Similar Projects
Up to this point in time, no other cold storage post-harvest projects have been undertaken in Uganda. However, similar projects have been undertaken in other countries with similar climates. For example, in Rwanda, Assistance à la Dynamisation de l'Agribusiness au Rwanda (ADAR) designed an evaporative cold storage structure for short-term storage right after harvest (up to 2 weeks time), which utilizes locally-available materials (Nenguwo, 2000).

In Uganda, solar powered refrigeration has been successfully used for medicine and vaccine preservation in recent vaccination campaigns (The Appropriate Technology Collaborative, 2010; The Jerusalem Post, 2011). A variety of technologies have been explored by scientists to provide cheap refrigeration for rural areas (Critoph & Thompson, 2000; Practical Action, 2010), and are listed in Appendix D: Cooling Systems.

Summary
In continuing to expand and take the CoolBot project to scale, the agroecological, financial, social and technical aspects of agriculture in Uganda must be understood, in order to ensure that the project is sustainable in the long-term.

High-value horticultural crops are promoted by governmental and NGO micro-finance institutions as a means of increasing the income of the rural poor. With cold storage, which extends the shelf-life of commonly cultivated crops, avoiding losses due to pests, fungi and bacteria, up to 35% more of the agricultural output in Uganda can be sold, which may be a step towards moving rural households out of subsistence agriculture,and into commercial agriculture.

However, the complicated nature of land ownership in Uganda may prove to be a barrier to small-scale entrepreneurial agricultural enterprises. Micro-financing options are expected to increase in accessibility in order to better meet the needs of resource-poor farmers. Ultimately, access to electricity and other power systems will be one of the most important factors in determining the economic feasibility and possible locations of the CoolBot or other cold storage systems in Uganda.

III. Methodology

Stakeholders Analysis

In order to identify and assess the importance of key parties involved in the development and deployment of the CoolBot system in Uganda, we conducted a stakeholder analysis. Within this process, stakeholders were organized according to their impact and influence levels (Fig. 1). "Impact" measures the degree of change they will experience in response to the project, and "influence" measures their degree of support for the project's objectives.

Figure 1: Stakeholders Analysis

Stakeholders who will be highly impacted by the project and have had high influence on project development are critical to this initiative, as they will be the primary decision makers in the process, and thus their opinions matter most. Those stakeholders are the Reach Your Destiny (RYD) Consult Ltd, and the USAID/ Horticultural Collaborative Research Support Program at

UC Davis. The aim of RYD's involvement in this project is to better understand the CoolBot technology in order to provide affordable coolrooms for smallholder vegetable producers in Uganda. The goal of the Horticulture CRSP, with funding from USAID, is to invest in horticultural development initiatives that advance the socioeconomic status of the rural poor by enabling income generating opportunities, such as high-value horticultural production. Both organizations will be highly impacted by the success of the CoolBot project in terms of future funding and taking the project to scale.

Stakeholders with high influence on the project but who receive little direct benefit (Bill and Melinda Gates Foundation) should be kept informed of project developments. Those that are highly impacted by project outcomes but have low influence, are the Farmers and Customers. D-Lab and Store-it-Cool, LLC fall somewhere in the middle. Farmers and customers are those on the ground in Uganda whose day-to-day economic activity will be directly impacted by the CoolBot technology. The D-Lab is the research and development component of the Program for International Energy Technologies (PIET) at UC Davis, whose goal is to both design and disseminate low-cost, clean and efficient intervention technologies in developing countries. While the impact of these groups is high, their influence is relatively low. Finally, the Bill and Melinda Gates Foundation is a non-profit organization dedicated to addressing global inequities. Though it will received little direct impact from the project itself (it is a relatively small project for such a large organization), it does have high influence over the CoolBot project, as it provides funding, and should therefore be kept informed and satisfied.

Essentially, the stakeholders consist of individuals, groups, and institutions as both beneficiaries and funders. While the farmers will be impacted the most by this project, their influence is low in the development of the CoolBot project, as they are the recipients of this technology chosen by Reach Your Destiny Consult Ltd, and thus their involvement in the analysis of the project is limited. Notable however, is that their decision as to whether or not to invest in the CoolBot system ultimately exposes them to the most risk, and perhaps more effort should be made to increase their involvement in this process to analyze the feasibility of the CoolBot system in Uganda.

Simulations & Scenarios

Introduction
To evaluate the economic feasibility of the CoolBot coolroom system in Uganda we used Excel and HOMER, a software developed by the National Renewable Energy Laboratory (NREL), to optimize micro-grid electricity generation. Using our Excel model we simulated the thermal behavior of the coolroom and we calculated the total electrical load (i.e. the electricity needed by the AC to keep the temperature and humidity under specified conditions). The model has been developed by our team and is based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) guidelines. The electrical load calculated in this way feeds into HOMER, which evaluates the most cost-effective combination of equipment to power the coolroom. This cost information is combined with the benefit analysis into a cost-benefit analysis

and graphed in Excel. A sensitivity analysis is also performed on the most important variables.
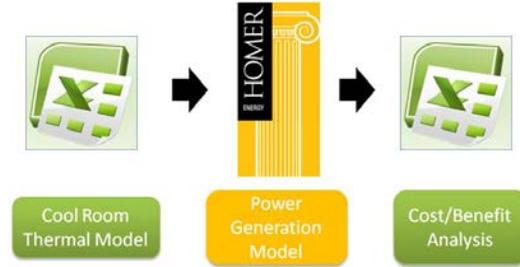
Methodology

A. Cool Room Thermal and Electrical Model (Excel)

I. Assumptions
- Temperature inside the Cool Room is kept at 40°F
- Weather Data (temperature, humidity, wind) were taken from the BBC Weather website (BBC 2011) and cross-referenced with NASA database (NASA 2011)
- To calculate the daily thermal load we modeled an average day of the year, 24 hours, instead of modeling 365 days. This assumption is valid because the seasonal variation in temperature and humidity in Uganda are substantially small (60-80 °F and 70-90% humidity ratio). Note that in the HOMER model, instead, we calculated 365 days of solar radiation, because such precision is needed to assess the power output of the PV panels.
- Sun radiation is based on the NASA (NASA 2011) and NREL database (provided with HOMER)
- Insulation of the coolroom is based on the information we received from Reach Your Destiny Consult on material currently used at the test site in Arua district (resulting in a best-case scenario of of R-20 insulation on the roof and R-22 on the walls)
- Since data on internal gains, infiltrations, and latent load were difficult to assess without detailed information on construction and operation, we applied a safety factor of 1.7 on the sensible load.
- The efficiency of the refrigerator (EER) is 9 (which takes into account the reduction in efficiency due to the re-heating of the cooling coil of the air conditioning unit when the ice is melted by a small heater, provided by the CoolBot)

II. Methods
The thermal and electrical load takes into account conduction, convection and thermal radiation through the walls and the ceiling, as well as solar radiation on the roof and walls. The load also calculates internal gains, infiltrations, and latent load introducing a safety factor of 1.7. However, actual field measurements are needed to validate these calculations. An insulation value of R-20 (measurement of thermal resistance in English Units) on the roof and R-22 on the walls represent a best-case scenario using the local available material described by the client:
- walls: bricks, polythene bags filled with dried grass, straw from millet, rice, sorghum, papyrus and maize, cement
- roof: clay tiles covered by grass thatch, polythene sheets

- door: iron sheets + insulation materials like those found on the doors of a fridge

We assumed an air conditioner efficiency equal to 9, due to some losses for the specific application (higher difference in temperature inside-outside compared to normal operation conditions of a air conditioner and additional energy used to defrost the coils).

B. HOMER Model

I. Assumptions
We simulated three scenarios for electric generation:
- Grid (only available in urban areas)
- PV system
- Gasoline Generator

The three system are illustrated in Figure 2:
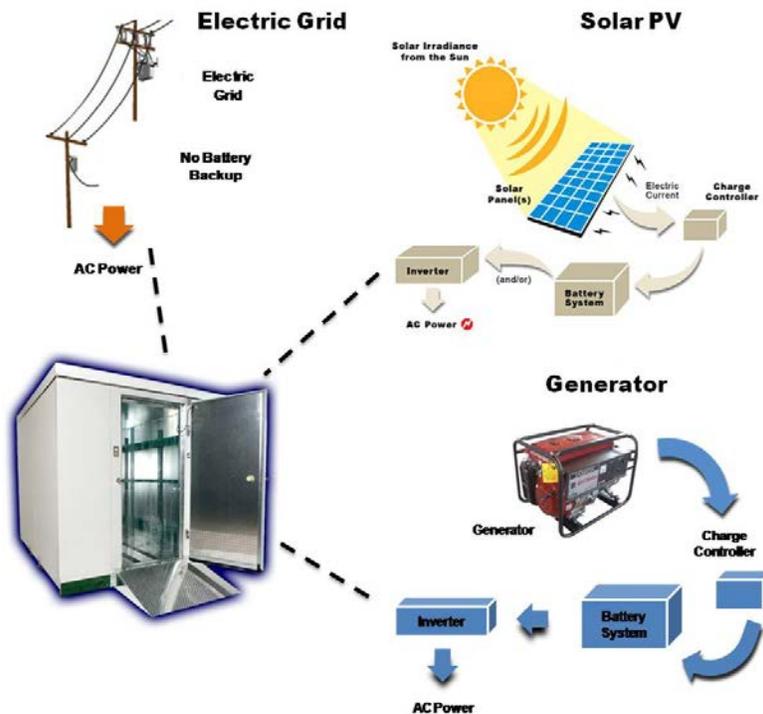
Figure 2. Three methods of power production

Inputs to our HOMER model come from the Excel load calculator and from Table1. Cost information have been obtained mainly by our local partner and complemented with our personal research. Costs do not include farm-related inputs (i.e. fertilizers, equipment, etc). Other assumptions include the use of the coolroom all year long (100% capacity factor), a lifetime of the PV system of 15 years, a lifetime of the gasoline generator of 10,000 hr, an interest rate of 0% and a project life of 20 years. At the end of the project the residual value of the equipment is cashed as salvage.

Table 1. HOMER inputs. From the excel load calculator.

Input to HOMER		
Cool room Costs (Shared)		
Capital Cost ($)	Air Conditioner	150
	Coolbot Control	100
	Hut	100
	Electric Installation for Cool Room	2000
	Technicians	1150
O&M cost ($/year)	Maintenance, Parts	50
PV System		
Capital Cost ($)	Solar Panel 75W (each)	320
	Installation of PV on Poles	3000
	Engineers	2000
	Deep Cycle Batteries (each)	150
	Inverter	400
	Solar Charger controller	75
O&M cost ($/year)	Maintenance, Parts (each panel)	10
Gasoline Generator System		
Capital Cost ($)	Generator + Installation	800
	Deep Cycle Batteries (each)	150
Fuel ($/liter)	Gasoline	1.36
O&M cost ($/h)	Maintenance, Parts	0.2
Grid System (no backup)		
Capital Cost ($)	Connection	200
Electricity ($/kWh)	Tariff	0.18
O&M cost ($/year)	Maintenance	20

C. *Benefits*

I. Assumptions
- Farmers receive market price for their crops, not farm gate price (net value of the product after the subtraction of marketing costs)
- Farmers sell and receive payment for their entire harvest (not consuming or giving away any proportion)
- Yields data is averaged for Uganda, and does not reflect management decisions by individual farmers or inherent variations across farms

II. Methods
Our benefit calculations focused on the following crops: onions, tomatoes, and cabbage (to be grown at our CoolBot prototype in Arua district); cassava and plantains (two of the most widely grown food crops in Uganda); as well as milk and fish (high value non-horticultural crops, for comparison purposes). Yields (kg/ha/year) were based on average data for Uganda for each of the aforementioned crops, and may not reflect actual farmer yields at a specific site (See Appendix A: Farm Size and Average Yields). Yields per farm per year were calculated using

average farm sizes for specific farmer classes in Uganda, and percentage of land devoted to each crop, which varied based on farm size (See Appendix A: Farm Size and Average Yields):

$$\text{Yield per Farm (kg/year)} = \text{Farm Area (ha)} \times \text{\% Land per Crop} \times \text{Yield (kg/ha/year)}$$

All prices were based on the January 2011 Consumer Price Index (CPI) for the region of Arua (See Appendix C: Cost Analysis). Some price variation is evident across regions, and benefit calculations should thus be region-specific. Based on the assertion by the Uganda Bureau of Statistics that consumer prices have risen by 5% in the last year (UBS, 2011), we chose not to average prices over the year, to reflect a best-case scenario for farmer revenue.

We calculated yearly revenue using the equation:

$$\text{Revenue (USD/year)} = \text{Yield per Farm (kg/year)} \times \text{Price (USD/kg)}$$

Benefit was calculated by assuming that the benefit gained from the CoolBot was equal to the current post-harvest losses per crop. Post-harvest losses for horticultural crops was set at 30% (statistic from our local partners), for milk at 21% (Hemme & Otte, 2010), and for fish at 45% (Akande & Diei-Ouadi, 2010). To calculate benefit, the following equation was used:

$$\text{Benefit (USD/year)} = \text{Revenue} - \text{Revenue} \times (100\% - \%\text{Post-harvest Losses})$$

Using the aforementioned crops and data, we then calculated the yearly benefit for five different scenarios, using Excel. The number of farmers in each scenario are illustrative of different possible situations in which the CoolBot coolroom may be used (See Figure 3). Scenario 1 (Rural Farmers in Arua), is the prototypical situation of the CoolBot in Arua, based on the information given to us by our local partner (number of farmers and crops). Scenario 2 (Rural Cooperative) increases the number of farmers in the same rural setting to 40, while leaving the crops the same. Scenario 3 (Small Retailer) places the CoolBot in an urban area, with a reasonable amount of produce for a small shop (selling only 1-2 kilograms per crop per day). Scenario 4 (Dairy Cooperative) is also rural, with the same number of farmers as in our original Arua location (5 farmers), with a different product (milk, instead of horticultural crops). Scenario 5 (Fishermen) is urban, with a completely different set of assumptions, based on an average artisan fishing boat, working for most of the year.

Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Rural Farmers in Arua	Rural Cooperative	Small Retailer	Dairy Cooperative	Fishermen
5 farm families (5 men and their wives)	40 farm families	1 shop	5 farm families	1 boat
Total Land Area: 2 hectares	Total Land Area: 16 hectares		2 cows each	
Yield (per year):	Yield (per year):	Sells (per year):	Per cow:	Typical Catch Per Unit Effort (CPUE): 30 kg
Tomatoes: 220 kg	Tomatoes: 1760 kg	Cassava: 500 kg	350 L milk/year	Estimated Catches per Year: 300 (based on year-round fishing season)
Cabbage: 242 kg	Cabbage: 1942 kg	Plantains: 500 kg	Total Cooperative Yield (per year):	Total Boat Yield (per year):
Onions: 242 kg	Onions: 1942 kg	Tomatoes: 300 kg	3500 L (3615.5 kg)	9000 kg
		Onions: 300 kg		
		Cabbage: 300 kg		
		Milk: 600 L (619 kg)		

Figure 3. The five scenarios which simulate a variety of CoolBot locations and uses.

D. *Cost-Benefit Analysis*
To compare the costs versus benefits of each system, we computed and graphed the yearly benefit minus the annualized cost (Net Present Cost / Life of the System) of our various scenarios and power systems (Figure 2). We grouped each production scenario with the possible power systems (those scenarios in a rural location were not compared to the electricity system). A sensitivity analysis has been was conducted changing key variables.

E. Cool-room *Volume Limitations*
To take into account volume limitations of the coolroom, we used the size of the coolroom prototype in Arua district as our volume limitation for all scenarios. The dimensions of the prototype are a diameter of 2.1 meters by a height of 3 meters, giving a total volume of $10.39m^3$. The usable space inside the coolroom was then assumed to be 50% of the total volume, or $5.19m^3$.

The maximum volume of the crops in each scenario was calculated to be the sum of the volume of the total harvest of each individual crop, as though all crops were harvested and placed in storage at the same time, with no amount of crops being immediately sold or consumed. The average volume of the crops per scenario was then calculated to be the sum of the volume of the total harvest of each individual crop averaged over the storage time for that crop. It is a more realistic account of what may actually occur in terms of storage and usage of the coolroom, assuming most crops will not be harvested at the same time of year, since few farmers will harvest all product at the same time, and most will be selling some of their product as it is harvested (See Appendix E: Volume Limitations).

IV. Results/Recommendations

Results

D-lab I, 2011 15

HOMER optimizes the number of panels, batteries and generators needed to meet the electric load of the coolroom while minimizing the net present cost (NPC), that is the sum of all the cash flow during the 20 years of the project. Given the inputs, the results of this optimization are:
- Grid (no optimization needed if the system is connected to the grid)
- PV system (12 PV panels 75W each, 6 Trojan batteries, 1 inverter)
- Gasoline Generator (one 1000W gasoline generator, 8 Trojan batteries, 1 inverter)

Other combinations of components do not meet the load (with consequences on internal temperature of the coolroom) or have a higher NPC. The cost associated with these optimized results are presented in Table 2.

Table 2. Three Power Supply Systems and Associated Costs

Cost of the system	Total Capital Cost ($)	Operating Cost ($/y)	NPC ($)	Annualized Cost ($)
PV (0.9 kW, 8 batteries)	$ 15,675	$ 462	$ 24,918	$ 1,246
Gasoline Generator (1kW, 8 batteries)	$ 5,975	$ 1,754	$ 41,053	$ 2,053
Grid (no battery)	$ 200	$ 213	$ 7,965	$ 398

Table 2 compares the capital cost, operating cost, net present cost (NPC) and annualized cost of the three solutions. The best solution is clearly the grid, but its availability is limited to a few urban areas (5% electrification rate). In comparison to the other two options the photo-voltaic (PV) system has the highest capital cost (more than $15,000) and an average annualized cost (about $1,200/year). The gasoline generator has a lower capital cost (about $6,000) but the annualized cost is almost double compared to the PV solution. The cost of fuel and the frequent maintenance required by a generator accounts for the difference. Figure 4 provides a better understanding of the nominal (not discounted) cash flow during the 20 year project with the three options. The PV system has an expected lifetime of 15 years, therefore it must be bough twice during the 20 year project. The positive value for the PV system at the end of the 20th year is due to the resale of the PV equipment.
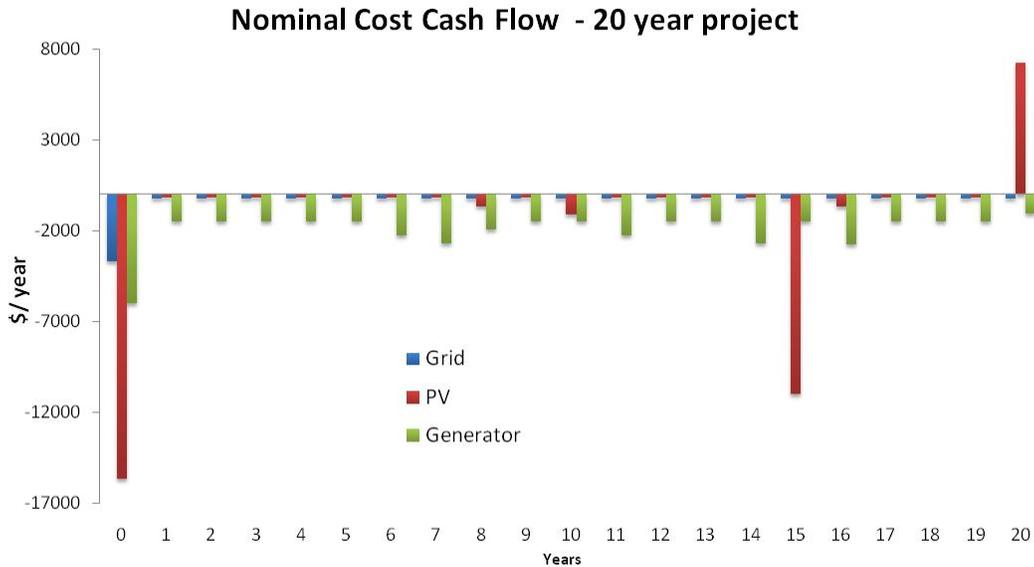
Figure 4. Nominal Cost (no Revenue) Cash Flow for the three generation system

To better understand what generates these costs we broke down the NPC of the three solutions into Coolroom related costs and Power Supply related costs. It is evident that, with the exception of the grid option, most of the cost goes into providing electricity to the system. Figure 5 illustrates graphically and numerically such results.

|	Grid	PV	Gasoline
Power	$3,465	$20,418	$36,553
Cool Room	$4,500	$4,500	$4,500
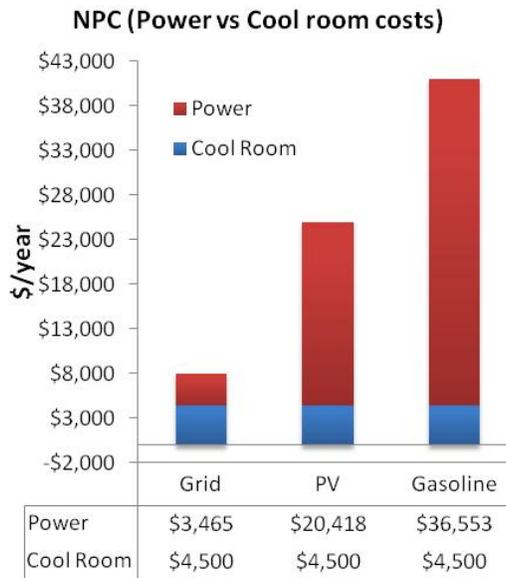
Figure 5. Cost breakdown between coolroom and power system.

The results of the benefit analysis are displayed in Figure 6. From left to right:
- Rural Farmers = $146
- Rural Cooperative = $117,
- Small Retailer = $337

- Dairy Cooperative = $37,
- Fishermen = $10,217

In the Small Retailer scenario we did not use markup prices, but we did account for that in our sensitivity analysis.
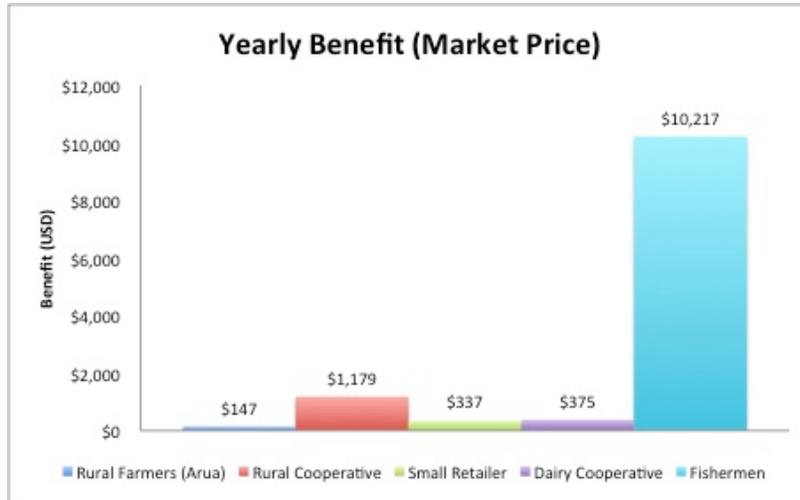

Figure 6: Yearly benefits in USD for each of the five output scenarios

The difference between the benefit and the cost of each system has been calculated as follows:

$$\text{Annual Profit} = \text{Benefit} - (\text{NPC} / \text{Lifetime of the Project})$$

The profit has been evaluated for each possible combination of scenarios and power options. Results are shown in Figure 7. From this analysis, it is easy to see that the project does not pay for itself in Scenarios 1-4 with any of the power option selected. Fishermen, on the other hand, can greatly benefit from the use of the CoolBot with an expected annual profit of more than $ 8,000 /year. This scenario assumes that additional fish can be sold without affecting the market price and that it can be sold locally (requiring no transportation in a cold truck). Another unproven assumption is that the CoolBot system can deliver temperatures cold enough for storing fish (however, we modeled the benefit for the fishermen based on the assumption that the shelf life would only be extended to 5 days, at the same temperature as the horticultural crops). In the case of fish, greater reductions in temperature may increase benefits even further. These assumptions need to be field tested to be considered reasonable.
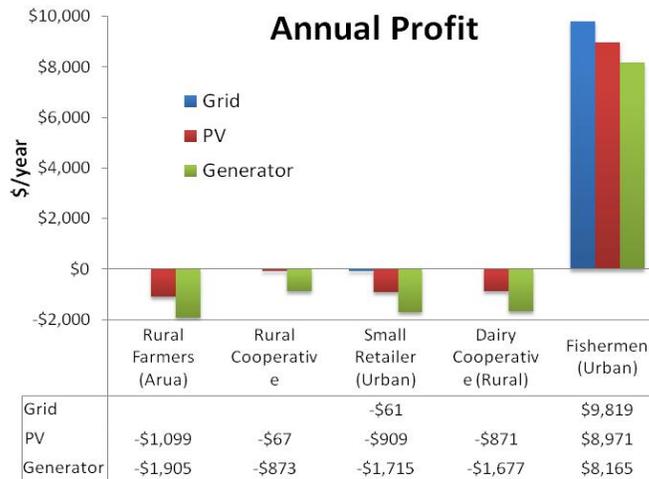
Figure 7. Annual profit of scenarios, using the CoolBot coolroom system.

Sensitivity Analysis
To evaluate the positive impact on the annual profit we conducted a sensitivity analysis on the following variables:

Insulation/AC efficiency/air leakage
Increasing insulation of the cool room to R-40, reducing air leaks, and increasing efficiency of the air conditioner leads to a reduced electric load, thus reducing the need for power, leading to a system downsize. This has a positive effect on the annual profit. Figure 8 (below) shows the effect on the annual profit for a Rural Cooperative (Scenario 2) using PV.
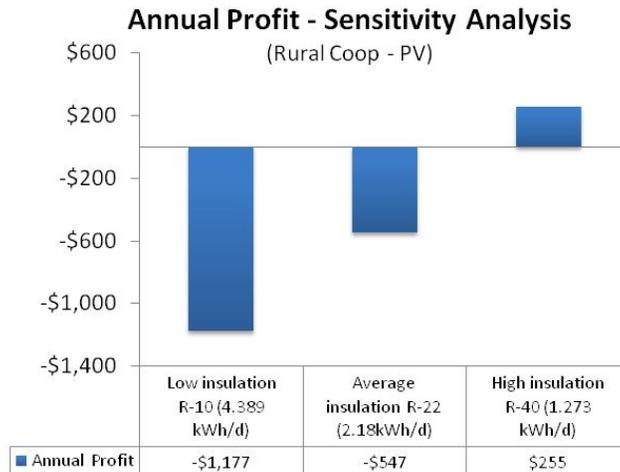
Figure 8. Insulation/AC efficiency/air leakage: (from left to right) varied the quality of insulation from values of R-10 to R-40 for the Rural Cooperative (Scenario 2), when utilizing a PV system.

Retail Markup Price
Multiplying the farmer price by a factor of 3 (simulating a retail markup) the retail profit margin is potentially significantly higher than the farm gate price.
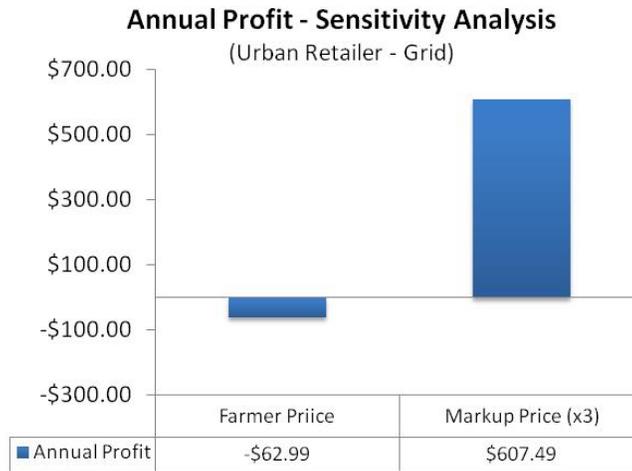
Figure 9. Retail Markup Price: multiplied farm gate prices by a factor of 3 in the Urban Retailer Scenario (scenario 3)

Lifetime of the PV system
If the PV system has a longer lifetime (more than 20 years) the annual profit becomes positive (see Fig. 10 below).
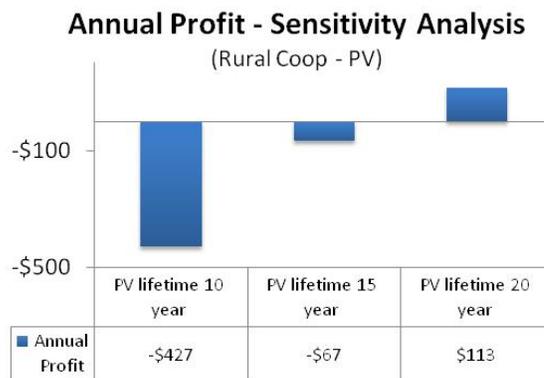
Figure 10. Lifetime of the PV system: (from left to right) varied from 10- 20 years

Discounted rate for cash flow (0%-3%-6%)
If we apply a discount rate to the cash flow both on the investment and on the revenue the annual profit shrinks, because we weight more the cash flow a the beginning of the project (i.e. the upfront cost). Figure 11 shows an example of this effect with the PV system in the Rural Cooperative Scenario 2.

Annual Profit - Sensitivity Analysis
(Rural Coop - PV)

	Interest Rate 0%	Interest Rate 3%	Interest Rate 6%
■ Annual Profit	-67	-264	-382
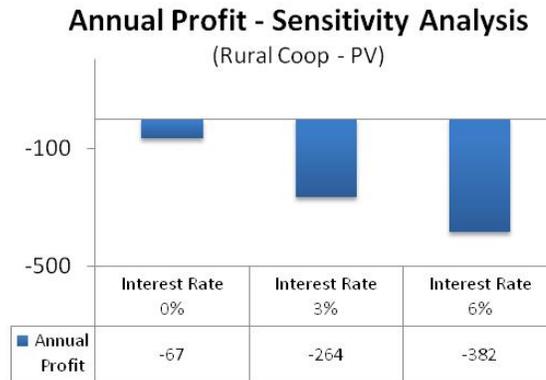
Figure 11. Discount Rate (from left to right) varied from 0% to 6%

Recommendations

The economic feasibility of the CoolBot coolroom system in Uganda is dependent upon careful analysis of the following:

- •Potential for revenue streams and increased income though cold storage.
- •Number of farmers utilizing the cool room
- •New and existing markets for a variety of horticultural products
- •Agricultural seasons/seasonality
- •Potential for the production of high-value
- •Optimization of production (increasing yields)

The cool room itself must:

- •Enable year-round use
- •Utilize best possible insulation materials
- •Be constructed in consideration of the lifetime of the system

A. Social and Political considerations

I. Government Policy and Local Systems

The proposed addition of the CoolBot cool room system in Uganda has implications for profound changes to take place in the structure of the market both locally and regionally, with unknown future consequences. Excess income derived from recouping post-harvest losses, as well as possible changes to the physical location of the buying and selling of fresh produce, has the potential to dramatically alter the local value chain. For example, the introduction of cold storage allows unsold produce to be stored for sale, changing the time and price at which product is sold. Our study suggests the need for a detailed analysis of the existing market system in order to determine the possible effects of the addition of a CoolBot cold storage system.

II. Gender

Gender is a key issue that may not always be apparent when proposing the adoption of

agricultural technologies and techniques. Uganda, like many African countries, is highly divided in the allocation of women's and men's responsibilities within the household, and agriculture is no different (Peterman, Quisumbing, Behrman, & Nkonya, 2010). Women tend to focus primarily on crops for household consumption, while men focus on high-value cash crops. Women's roles in agriculture tend to revolve around weeding, post-harvest processing, and food preparation, while men are responsible for marketing (Peterman, et al.). This division of labor between the sexes has implications for the use and ownership of a CoolBot coolroom system.

Likewise, gender affects land tenure and property rights. In both the traditional and official landholding systems, women are not likely to inherit or own property (Bruce & Marquardt, 1998). Despite women's movements since the 1990's to change aspects of the land tenure laws (such as a co-ownership clause), not much has been implemented and women continue to own only a small fraction of land in Uganda (Tripp, 2004). It is necessary to consider the gender gap when determining land ownership and roles within a new value chain as impacted by the new element of the CoolBot coolroom system.

III. Rural-Urban Migration and Ownership
Currently, only about 13% of the population of Uganda is urban, but the annual urban growth rate is 4.4% (CIA Factbook). Like so many African countries, the number of people living in urban areas is rapidly increasing, which gives rise to a slew of social and cultural issues related to rural-urban migration, including increased need for urban employment, changes in the dynamics of rural households, and increased need for food and other necessities in urban centers (Black & Sward, 2009).

New technological opportunities require different strategies depending on their implementation in either rural or urban settings. When determining the most productive placement of the CoolBot coolroom system within the value chain, the following elements should be considered:
- Training: how will the basics of food storage and CoolBot maintenance be communicated?
- Project ownership: who owns the land, the cool room structure? Who will be responsible for maintenance?
- Farmer group dynamics: Are there inequalities amongst members due to gender, social class, or other power structures?

B. Environmental and Health Considerations
I. Environmental Impact
It is recommended that the environmental impact of the CoolBot system, particularly in relation to its power source, be evaluated on a local scale. The direct implications of a generator, used to power the air conditioning unit, could include both increased noise levels and reduced air quality within the immediate vicinity. Additionally, production and harvest techniques change considerably in relation to the crop grown (i.e. cereals versus vegetables). Indirect environmental consequences could result from a change in the crop mix of the local farming systems, as more and more acreage is devoted to horticultural crops.

II. Health and Incorrect Cold Storage

Potential incorrect usage of the CoolBot system could have health implications in terms of food safety concerns. For example, if fresh products are not held at the appropriate temperature, the incidence of food rot and food borne diseases will increase. See Appendix B for appropriate temperatures and storage times for the five horticultural products selected for this study, as well as other high-value fresh food products of milk and fish. An education and extension program is recommended on the basics of cold storage.

C. Technical considerations

I. Cool Room Construction

Coolroom construction should be optimized through further research and experimentation. The current materials used for construction, size of the coolroom, and electrical load are not based on optimal conditions for cold storage, and could be improved. A more detailed analysis of the coolroom design is necessary to make recommendations on size, layout, and materials based on a best-case scenario. Insulation material in particular can have a dramatic effect on the efficiency of the CoolBot System, and various locally available options have not yet been tested for feasibility of use.

II. Power Source

The three power sources for the CoolBot system evaluated in this paper are the use of photo voltaic panels and an inverter, a gasoline generator, and a municipal electric grid. PV panels are used for the current coolroom model in Uganda, due to the unavailability of an electric grid. The economic feasibility of this project is severely hindered by the fact that off-grid electricity can cost as much as 20 times more than grid electricity. However, as the possible placement of the cold storage room changes from a rural to an urban setting, the use of an electric grid may become possible. Careful protection of system components, such as batteries and inverters, must be considered.

The use of a diesel generator is recommended instead of a gasoline generator. Although this represents a higher initial cost, the maintenance cost is typically much lower and the generator lifetime is significantly higher. Diesel generators have a typical capacity of 3-6 kW; while this is greater than the power necessary to supply the air conditioning unit and the CoolBot, the capability of powering other devices has social and economic implications that must be considered for any system providing electricity.

D. Financial considerations

I. Financing Options

All options for financing this system in Uganda must be considered in terms of feasibility and availability. The cost of production for a small-scale horticultural farmer has not been considered within this evaluation, but since the market price of fresh product is quite low, these farmers lack the ability to capture economies of scale. Therefore, it is unlikely that an individual farmer could assemble the funds to meet the large up-front cost of the CoolBot coolroom system. The availability of local financing options, banking services, or co-op opportunities must be

evaluated if this system is to be recommended for placement elsewhere.

II. Selection of Products
The five horticultural crops used for this analysis were selected for their potential use in Arua District, Uganda. Fish was compared to the other agricultural products (vegetables, plantains and milk) since fish is high-value and post-harvest loss can be as high as 45%. Currently, there is no cold supply chain in Uganda right now for any of these products, though they are still sold and consumed. The use of the CoolBot storage for the fish market is an example of optimizing profits via high-value product selection.

Profits could also be maximized by increasing the total number of farmers who invest and utilize the coolroom. Increased yields could lead to greater profits as well, but this may necessitate a bigger coolroom, and hence a new model and market analysis would be needed. Again, implications for a change in the market price at any increase in the availability of horticultural products, either through improved post-harvest quality or increased yield, must be evaluated in terms of the impact on imports and exports.

Summary
Further evaluation of the local implications of a CoolBot cool room system is necessary in order to anticipate possible changes to the market structure and economy. Other yield-enhancing strategies should be utilized to further increase the potential income of small-scale farmers in Uganda, and an education and extension program is recommended to communicate the basic elements and consequences of cold storage. An evaluation of potential environmental impact to the local region is recommended, but a more detailed analysis of the cool room design is necessary to make recommendations on optimal size, layout, and construction materials . The use of a diesel generator is suggested instead of a gasoline generator, should a PV system prove not affordable or inadvisable. In any case, careful protection of system components from theft and weather must be considered, as well as the possibility of using the power system to supply power to other electrical devices. Various financing options must be analyzed in conjunction with other techniques to maximize profits for small-scale farmers. This analysis suggests joint ownership of the cool room system in co-operatives and simultaneous efforts to increase yields through improved farming techniques.

Conclusion

The current CoolBot coolroom system designed for use in Arua district, Uganda consists of three basic components: a power supply, a room, and a air conditioning unit attached to a CoolBot. Ultimately, the impact of the implementation of new products like the CoolBot system, should be considered before proposing any change to the current value system. In particular:

- The issue of land tenure in this particular project is of utmost importance. The farmers' likeliness to build and maintain the CoolBot system is highly correlated with whether or not they are registered landowners.

- Since the cold storage building is communally-owned, the relationships between farmers utilizing the building is key, especially in terms of mixed-gender groups, where women may be marginalized, especially if the men are the landowners.
- Since agricultural productivity decreases on mixed-gender and women-only farms due to household dynamics, this may be a key component in determining the composition and number of farmers utilizing the CoolBot.
- Rural-urban migration also plays a role in the maintenance of the system. If men are likely to migrate to urban centers, are women able and willing to maintain the system?
- Women tend to produce crops for home consumption, while men tend to produce cash crops. The CoolBot system is geared towards cash crop production (in order to make a profit). Will this marginalize women, especially in mixed-gender target groups?

No technological change takes place in a vacuum, particularly those which influence the system of food supply. The CoolBot cold storage system has the potential to increase income through decreased post-harvest losses of horticultural crops. However, successful use of this technology is dependent on careful consideration of power supply availability, financing options, and possible effects on the current market structure.

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V. Appendices

Appendix A: Farm Size and Average Yields

Average Farm Sizes/Percentage of Farmland Devoted to Crop

	Small Farms	Mid-Size Farms	Large Farms	Average
Farm Size (Hectares)	0.40	1.94	17.40	1.98
Percent of land devoted to cassava	0.119	0.135	0.143	0.128
Percent of land devoted to banana	0.251	0.209	0.197	0.228
Average value of output per acre (US$)	87	41	16	61
Percentage of Land devoted to horticulture				0.03

Average Farm Yields (Based on Land Percentage Devoted to Crop)

	Average Yield (t/ha)	Average Yield (kg/ha)	Small Farms (kg/yr)	Mid-size Farms (kg/yr)	Large Farms (kg/yr)	Average (kg/yr)
Cabbage	4	4000	48.56	233.10	2,088.18	237.96
Cassava	10.4	10400	500.84	2,727.26	25,879.48	2,639.72
Onions	4	4000	48.56	233.10	2,088.18	237.96
Plantains	5.89	5894	598.69	2,392.85	20,205.17	2,664.76
Tomatoes	3.63	3625	44.01	211.25	1,892.41	215.65

Average Fishing Yields (Per Boat)

	Catch Per Unit Effort (CPUE) (kg/day)	Season (Days/Year)	Average Fisherman Output (kg/year)
Fish	30	300	9000

Average Dairy Yields (Per Farm)

	Per Cow Production (L/year)	Average Number of Cows/Farm	Avg Farm Output (L/year)	Avg Farm Output (Kg/year)
Milk	350	2	700	723.1

Appendix B: Post-harvest storage of five horticultural products, milk and fish

	Storage Temperature (°C)	Relative Humidity	Freezing Injury (°C)	Storage Life
Round Cabbage	0 °C	>95%	< -0.9 °C	Early Crop: 3-6 weeks
				Late Crop: 5 to 6 months
Cassava	0 – 5 °C	85-90%		1-2 months
Onion	0 °C	65-70%	0 °C	Mild Variety: 0.5 to 1 month
				Pungent Variety: 6 to 8 months
Plantain	11°C	90-95%	10°C	3-5 weeks
Tomato	7°C – 10°C	90-95%	Stored longer than 2 week: 10°C	Firm-ripe: 3-5 days
			Stored longer than 6-8 days: 5°C	
Milk	5 °C	NA	0 °C	5 days

Fish	5 °C	NA	NA	5 days

Appendix C: Cost Analysis

Grid Calculations

Prj Capital cost	3500	
Grid Connection Cost	200	
Prj running cost	50	
OM cost/y	20	
Load	2.18	kWh/d
Cost Elect	0.18	$/kWh
Interest	0%	
LOAD FACTOR	100%	

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash Flow	3700	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213
Coeff	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Discounted	3700	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213	213
As cost	-3700	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213	-213

NPC	7,965 $
LCOE	0.50 $
Annualized Cost	398 $

PV Calculations

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	tot
PV	-10,800	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-10,920	-120	-120	-120	-120	7,080	-16,800
Trojan T-105	-900	-30	-30	-30	-30	-30	-30	-30	-30	-30	-930	-30	-30	-30	-30	-30	-30	-30	-30	-30	-60	-2,430
Converter	-475	0	0	0	0	0	0	0	-475	0	0	0	0	0	0	0	-475	0	0	0	238	-1,188
Other	-3,500	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-4,500
Entire system	-15,675	-200	-200	-200	-200	-200	-200	-200	-675	-200	-1,100	-200	-200	-200	-200	-11,000	-675	-200	-200	-200	7,207	-24,918

NPC	24,918 $
LCOE	1.59 $
Annualized Cost	1,246 $

Gasoline Generator Calculations

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	tot
Generator 1	-800	-1,399	-1,399	-1,399	-1,399	-1,399	-2,199	-1,399	-1,399	-1,399	-1,399	-2,199	-1,399	-1,399	-1,399	-1,399	-2,199	-1,399	-1,399	-1,399	-1,226	-31,011
Trojan T-105	-1,200	-40	-40	-40	-40	-40	-40	-1,240	-40	-40	-40	-40	-40	-40	-1,240	-40	-40	-40	-40	-40	5	-4,355
Converter	-475	0	0	0	0	0	0	0	-475	0	0	0	0	0	0	0	-475	0	0	0	238	-1,188
Other	-3,500	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-4,500
Entire system	-5,975	-1,489	-1,489	-1,489	-1,489	-1,489	-2,289	-2,689	-1,964	-1,489	-1,489	-2,289	-1,489	-1,489	-2,689	-1,489	-2,764	-1,489	-1,489	-1,489	-1,033	-41,053

NPC	41,049 $
LCOE	2.58 $
Annualized Cost	2,052 $

Benefit

	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Revenue - avg
Rural Farmers (Arua)	Scenario 1		147	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147
Rural Cooperative	Scenario 2		1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179	1179
Small Retailer (Urban)	Scenario 3		337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337
Dairy Cooperative (Rural)	Scenario 4		375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375
Fishermen (Urban)	Scenario 5		10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217	10217

Appendix D: Cooling Systems

A. *Passive Evaporative Cooling*

Passive evaporative systems require low capital and running costs (no electricity is needed). They do not work well in high humidity climates, and Uganda has 70-90% humidity during most part of the year) and they only allow temperature reduction to 10-25°C (local crops need lower temperatures). One application is known as "pot-in-pot" refrigerator, and it dates back to the

Ancient Egyptians. In 2009, a young UK student (Emily Cummins) re-engineered this old technology into a new portable product for little volumes, attracting the press interest. (Dailymail, 2009; Wikipedia, 2010a).
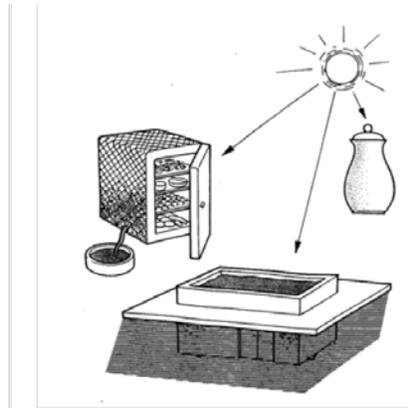

Figure 1: Passive Evaporative Cooling (Practical Action, 2010)

B. *Absorption (& Adsorption) Heat driven*
Adsorption refrigeration cycles rely on the adsorption of a refrigerant gas into an adsorbent (solid) at low pressure and subsequent desorption by heating. The adsorbent acts as a 'chemical compressor' driven by heat. The subsequent return to the initial state takes in heat and produces the required refrigeration effect. (Critoph & Thompson, 2000). Absorption cycles work in the same way but they use a liquid (absorbent) instead of a solid (adsorbent). The advantage of this technology is that it can be designed without moving parts, reducing the need for maintenance. It is easy to manufacture and compatible with different fuel sources (solar, fossil fuel, biomass). Unfortunately it is not readily available on the market, being mainly in research stage: different alternative designs and materials have been tested in the field in the last decade (Critoph & Thompson, 2000). The system has lower efficiency (COP), compared to mechanical vapor-compression cycles (Wang & Oliveira, 2005).
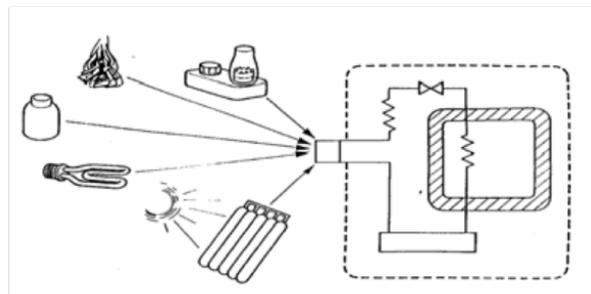
Figure 2: Absorption Cycle (Practical Action, 2010)

C. *Mechanical Vapor-Compression*
With this technology, heat is removed from a low-temperature space (the cold room) and ejected to a high-temperature sink (outside air) with the help of external work generated by a compressor. This is usually the solution that offers the lowest capital cost in case of access to the grid. If a reliable source of electricity is not available, the system can be designed to work with diesel generators or photo-voltaic panels with batteries for nighttime operation. "CoolBot" is a variation of this technology, and it uses a cost-effective AC product, instead of a more complex ad-hoc system, to cool the room to temperature up to 2-3°C.
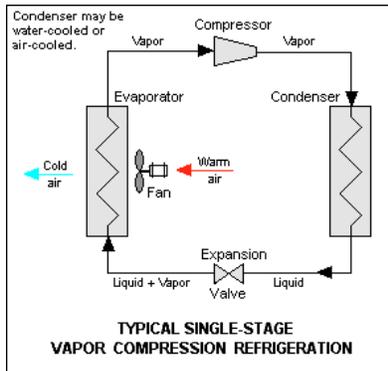

Figure 3: Vapor-Compression Cycle (Wikipedia, 2010b)

Appendix E: Volume Limitations

Please note: in all scenarios, the "Average Volume" is less than the proposed usable 50% volume for the coolroom (5.19m³), and in some cases, the "Maximum Volume" is also lower.

Scenario 1: Rural Farmers Arua

	Possible Harvests/Year	Total Harvest (Kg)	m3/Kg	Max Storage Time (Year)	Avg Volume	Max Volume (m3)
Cassava	1	0	0.0012	0.167	0.00	0.000
Tomato	2	220	0.0013	0.058	0.03	0.572
Onion	1	242	0.0018	0.667	0.29	0.436
Plantain	*	0	0.0010	0.096	0.00	0.000
Cabbage	2	242	0.0013	0.500	0.31	0.629
Milk	*	0	0.0010	0.014	0.00	0.000
Fish	*	0	0.0014	0.014	0.00	0.000
*Year-Round				Total Volume (m3)	0.64	2

Scenario 2: Rural Cooperative

	Possible Harvests/Year	Total Harvest (Kg)	m3/Kg	Max Storage Time [Year]	Avg Volume	Max Volume (m3)
Cassava	1	0	0.0012	0.167	0.00	0.000
Tomato	2	1760	0.0013	0.058	0.26	4.576
Onion	1	1942	0.0018	0.667	2.33	3.496
Plantain	*	0	0.0010	0.096	0.00	0.000
Cabbage	2	1942	0.0013	0.500	2.52	5.049
Milk	*	0	0.0010	0.014	0.00	0.000
Fish	*	0	0.0014	0.014	0.00	0.000
*Year-Round				Total Volume (m3)	5.12	13

Scenario 3: Small Retailer

	Possible Harvests/Year	Total Harvest (Kg)	m3/Kg	Max Storage Time [Year]	Avg Volume	Max Volume (m3)
Cassava	1	500	0.0012	0.167	0.10	0.575
Tomato	2	300	0.0013	0.058	0.04	0.780
Onion	1	300	0.0018	0.667	0.36	0.540
Plantain	*	500	0.0010	0.096	0.05	0.500
Cabbage	2	300	0.0013	0.500	0.39	0.780
Milk	*	520	0.0010	0.014	0.01	0.599
Fish	*	0	0.0014	0.014	0.00	0.000
*Year-Round				Total Volume (m3)	0.95	4

Scenario 4: Dairy Cooperative

	Possible Harvests/Year	Total Harvest (Kg)	m3/Kg	Max Storage Time [Year]	Avg Volume	Max Volume (m3)
Cassava	1	0	0.0012	0.167	0.00	0.000
Tomato	2	0	0.0013	0.058	0.00	0.000
Onion	1	0	0.0018	0.667	0.00	0.000
Plantain	*	0	0.0010	0.096	0.00	0.000
Cabbage	2	0	0.0013	0.500	0.00	0.000
Milk	*	3616	0.0010	0.014	0.05	3.491
Fish	*	0	0.0014	0.014	0.00	0.000
*Year-Round				Total Volume (m3)	0.05	3

Scenario 5: Fishermen

	Possible Harvests/Year	Total Harvest (Kg)	m3/Kg	Max Storage Time [Year]	Avg Volume	Max Volume (m3)
Cassava	1	0	0.0012	0.167	0.00	0.000
Tomato	2	0	0.0013	0.058	0.00	0.000
Onion	1	0	0.0018	0.667	0.00	0.000
Plantain	*	0	0.0010	0.096	0.00	0.000
Cabbage	2	0	0.0013	0.500	0.00	0.000
Milk	*	0	0.0010	0.014	0.00	0.000
Fish	*	9000	0.0014	0.014	0.17	12.600
*Year-Round				Total Volume (m3)	0.17	13

Values used in above calculations:

1. Cassava:
   1. Maturity: 10 months
   2. Storage Time: 2 months
2. Tomato:
   1. Maturity: 80 days
   2. Storage Time: 3 weeks
3. Onion:
   1. Maturity: 9 months
   2. Storage Time: 8 months)

4. Plantain:
   1. Maturity: Year-Round
   2. Storage Time: 5 weeks
5. Cabbage:
   1. Maturity: 180 days
   2. Storage Time: 6 months
6. Milk:
   1. Maturity: Year-Round
   2. Storage Time: 5 days

7. Fish:
    1. Maturity: Year-Round
    2. Storage Time: 5 days