EVAPORATIVE COOLING BEST PRACTICES

Producing and using evaporative cooling chambers and clay pot coolers

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June 2018

D-Lab

D-Lab

MIT D-Lab works with people around the world to develop and advance collaborative approaches and practical solutions to global poverty challenges. The program's mission is pursued through interdisciplinary courses, research in collaboration with global partners, technology development, and community initiatives — all of which emphasize experiential learning, community-led development, and scalability. This guide was made possible through support from Malcom B. Strandberg.

movement

Movement e.V. is a German Association which works in Burkina Faso in close collaboration with local people for a sustainable development. We are convinced that development cooperation cannot be a one-sided undertaking, but involves open collaboration and intercultural exchange. Since 2008 Movement implements projects in the field of appropriate technologies (solar powered grain mill, clay pot cooler), fair trade, and ecological land use.

World Vegetable Center

The World Vegetable Center, an international nonprofit research and development institute, is committed to alleviating poverty and malnutrition in the developing world through the increased production and consumption of nutritious and health-promoting vegetables. The World Vegetable Center helps farmers increase vegetable harvests, raise incomes in poor rural and urban households, create jobs, and provide healthier, more nutritious diets for families and communities.

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Introduction

When affordable and effective post-harvest storage solutions are in short supply, populations will often experience vegetable spoilage, loss of income, lack of access to nutritious foods, and large amounts of time spent purchasing vegetables, particularly in rural communities. Devices such as evaporative cooling chambers (ECCs) and clay pot coolers are simple and inexpensive ways to keep vegetables fresh without the use of electricity. These devices function according to a basic principle called “evaporative cooling,” where the evaporation of water from a surface removes heat, creating a cooling effect. Evaporative cooling can improve vegetable storage shelf life by providing:

- A stable storage environment with low temperature and high humidity, which reduces the rate of respiration and water loss and spoilage in most vegetables
- Protection from animals and insects that contaminate and eat the vegetables

The improved storage environment can have positive impacts including reduced post-harvest losses, less time spent traveling to the market, monetary savings, and increased availability of vegetables for consumption. These devices can also have farther-reaching impacts, particularly on women, who often make pottery and could benefit economically from producing clay pots with local materials, as well as selling fruits and vegetables in more flexible markets that have access to evaporative cooling technology.

Left: A clay pot cooler with a pot-in-pot configuration
Right: An evaporative cooling chamber (ECC) constructed from bricks with a cover made from dry grass and wood

Several hot and dry regions throughout the world could potentially benefit from evaporative cooling, including North Africa, the Sahel region of Africa, the Horn of Africa, southern Africa, the Middle East, arid regions of South Asia, and Australia. Through this document and related research, we hope to increase awareness of evaporative cooling technologies to improve their dissemination in appropriate contexts. This guide is intended to provide practical information about ECCs and clay pot coolers, including:

- How to determine if they are suited for a particular context
- Construction using locally available materials
- Increasing awareness and adoption of locally made products

Two vendors of vegetables with a clay pot cooler at the market in Ouahigouya, Burkina Faso.

The ECC and clay pot cooler devices in this study function on the principle of direct evaporative cooling, where heat is removed as water evaporates from the surface of the storage device. The evaporative cooling effect causes a decrease in temperature and an increase in the relative humidity inside the storage device, conditions that increase the shelf life of many vegetables. Water must be added at regular intervals to maintain the cooling effect. The watering frequency required can vary from several times a day to only a few times a week, depending on the storage device's material and design as well as the weather conditions. In hot and dry climates (greater than 25 °C and less than 40% humidity) ECCs and clay pot coolers can be expected to provide a storage environment with humidity greater than 80% and temperature at least 8 °C lower than the maximum daily ambient temperature. Additional details on the performance of evaporative cooling devices can be found in:
"*Evaporative Cooling Technologies for Improved Vegetable Storage in Mali - Evaluation Report*".

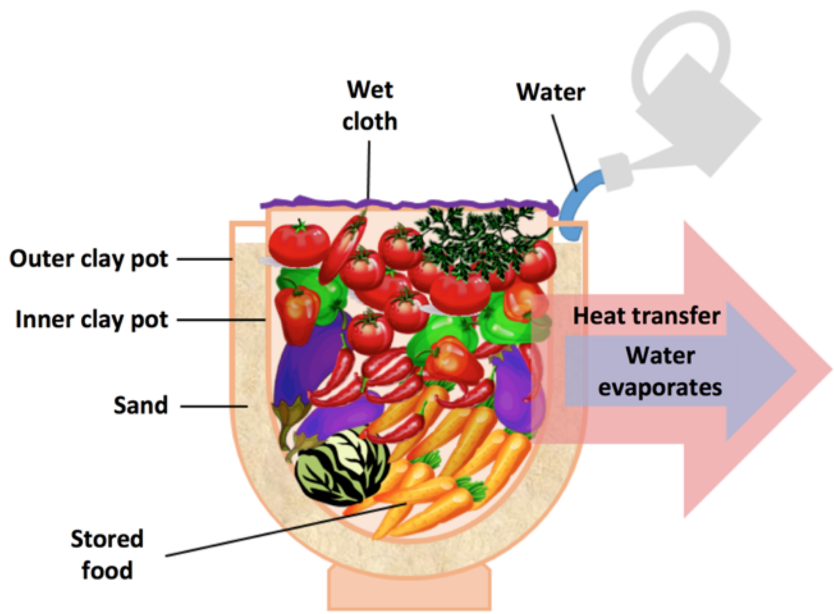

Diagram of a clay pot cooler with a pot-in-pot configuration, covered by a wet cloth.[1]

The information presented in this guide is intended for any organization or individual that may be interested in distributing and/or promoting these technologies to vegetable producers, distributors, and consumers who are looking for improved vegetable storage solutions. Examples include non-governmental organizations (NGOs) and government agencies that promote horticultural best practices, or social enterprises and local businesses that may have an interest in producing and marketing vegetable storage technologies.

[1] Adapted from Peter Rinker, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=33444154, Accessed January 3, 2018

Suitability of Evaporative Cooling Devices

Evaporative cooling devices such as evaporative cooling chambers (ECCs) and clay pot coolers are not suitable for all contexts, and several factors should be assessed to determine if a device will meet user needs in a particular setting. Below is a list of key considerations[2]:

- **Operating conditions:** Specific conditions are required for evaporative cooling devices to operate effectively:
    - Low relative humidity (less than 40 %)
    - High temperature (daily maximum above 25 °C)
    - Access to water, which must be added for evaporative cooling to work
    - Availability of shady, well-ventilated locations for ECCs and clay pot coolers
- **Need:** The storage conditions provided by evaporative cooling devices must meet users' needs. Potential users should consider:
    - Optimal storage conditions for different vegetables
    - The scale of vegetable storage needed
    - Variations in the need for vegetable cooling and storage throughout the year
- **Value:** The cost of the ECC or clay pot cooler must be affordable and justified by the benefits that will be realized due to its improved storage. Potential users should evaluate:
    - Local availability and affordability of materials to construct an ECC or clay pot
    - Potential benefits of evaporative cooling devices, such as time and money saved, increased vegetable availability, improved hygiene, and convenience

In the following sections, we discuss these considerations along with specific insights from research conducted by MIT D-Lab.

Operating conditions

Several key considerations are important for determining if an evaporative cooling device will provide effective cooling and storage. ECCs and clay pot coolers provide the most benefits when they are used in low ***humidity*** climates (less than 40% relative humidity), the ***temperature*** is relatively hot (maximum daily temperature greater than 25 °C), ***water*** is available to add to the device between one and three times per day, and the device can be located in a ***shady and well-ventilated area*** (see the "Best Practices for Use" section). If any of these key criteria cannot be met at the time when improved vegetable storage is needed, then ECCs or clay pot coolers may not provide sufficient benefits to justify their use.

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[2] Adapted from "*A Review of Porous Evaporative Cooling for the Preservation of Fruits and Vegetables*" (Odesola & Onwuka, 2009)

Need for improved post-harvest vegetable cooling and storage

Improved post-harvest vegetable cooling and storage technologies have the potential to provide benefits along several points of the post-harvest horticulture value chain, including to farmers, traders, and consumers. However, the specific vegetable storage needs of a particular user should be considered before deciding to use an evaporative cooling device such as an ECC or clay pot cooler. Some key considerations follow.

What type of vegetables or other products are in need of improved storage?

ECCs or clay pot coolers provide benefits if post-harvest vegetable spoilage is the result of exposure to high temperatures, low humidity, animals, or insects. Some examples of vegetables that are particularly vulnerable to these conditions include eggplants, tomatoes, leafy greens, peppers, and okra. See the "Conclusions and Additional Resources" section for a more complete list of vegetables that can benefit from storage in an evaporative cooling device. Non-electric evaporative cooling devices – such as ECCs and clay pot coolers – are **not** suitable for items that require sustained temperatures below 20 °C (medicine, meat, and dairy products) or foods that require a low humidity environment (onions, coffee, garlic, millet, and other grains).

What volume of vegetables needs to be stored at any one time?

It is necessary to estimate the volume of vegetables in need of improved storage at any given time to determine the appropriate size of the evaporative cooling device. If the vegetables can fit into a clay pot with a capacity of 150 liters or less, then a clay pot cooler is most appropriate. Individuals or groups that need to store larger amounts of vegetables can consider an ECC. A brick ECC can be designed to accommodate the storage volumes between roughly 500 and 5,000 liters (see the "Construction of Evaporative Cooling Chambers" section).

How often is improved vegetable storage needed?

Variations in the need for improved vegetable storage can arise due to seasonal growing and harvest cycles, vegetable production surpluses relative to local demand, and climate variations. It is important to determine if proper operating conditions exist for evaporative cooling to effectively provide benefits during the time when vegetable storage is needed, and if the need for improved vegetable storage is frequent enough that the value an ECC or clay pot cooler can provide is greater than its cost.

Right: Cabbages, eggplants, and peppers, and lettuce stored on a wet cloth.

Value that ECCs and clay pot coolers provide in relation to their cost

The cost of constructing a device should be estimated to determine if investing in an ECC or clay pot cooler is justified. Relevant materials must be locally available and affordable. A description of the materials needed to construct ECCs or clay pot coolers can be found in the next section.

The benefits must be greater than the cost to justify the construction or purchase of an ECC or clay pot cooler. Among the benefits that should be considered when making this determination are:

- Financial savings due to reduced food loss
- Time and money saved travelling to the market
- Increased availability of vegetables to a family
- Improved hygiene of the vegetables
- Convenience

Additionally, an end user must either be able to afford the cost of the device or have access to a financing plan that will allow for them to pay for the device after the financial benefits of improved storage have accumulated.

Overall, the evaporative cooling and storage technologies discussed here have the potential to provide effective post-harvest vegetable storage in an appropriate context. Based on the considerations outlined in this section, we have developed an interactive Microsoft Excel-based "*Evaporative Cooling Decision Making Tool*" to help determine if evaporative cooling devices are suitable for a particular context and guide the calculation of potential financial savings.

Farmers in need of improved vegetable storage in Bankass, Mopti, Mali

Construction of Evaporative Cooling Chambers

Evaporative cooling chambers (ECCs) – also known as "zero energy cool chambers (ZECCs)" – can be made from locally available materials including bricks, sand, wood, dry grass, gunny/burlap sack, and twine. The brick ECC was originally developed in India by Susanta K. Roy and D.S. Khuridiya in the early 1980s (Roy & Khurdiya, Keep vegetables fresh in summer, 1982; Roy & Khurdiya, 1985) to address fruit and vegetable post-harvest losses, especially in rural areas where electricity is non-existent. Roy and Khuridiya's ECC design is composed of a double brick wall structure, supported by a base layer of brick, and covered with a straw mat. The space in between the two brick walls is filled with sand, which retains the water that is added. Inside the ECC, food is placed in unsealed plastic containers, which keeps the vegetables off the ECC's floor and allows them to breathe and be exposed to the cool, humid air inside the device. ECCs can provide a temperature up to 10-15 °C cooler than the temperature outside the chamber and maintain a high humidity of about 95%, which can significantly extend the shelf life of many vegetables.

Due to their relatively large size, ECCs are most suitable for farmers with large production quantities, farming groups, or farming cooperatives. The size of an ECC can be chosen to meet a range of user storage needs; however, the cost can vary significantly based on desired size and local cost of materials. Because ECCs can be constructed over a range of sizes, it is important to select an appropriate size according to the need, to avoid over-building and spending more money than is needed.

Vegetables stored in an evaporative cooling chamber

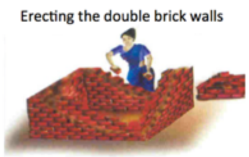
Evaporative cooling chamber materials and construction

An evaporative cooling chamber (ECC)[3] can be built simply with local materials such as bricks, sand, wood, straw, dry grass, gunny/burlap sack, and twine. Follow these steps to build ECC:

1)

Make a foundation of approximately 165 cm x 115 cm with bricks. The dimensions can vary according to the storage volume needed

2)



Mount the double wall at approximately a height of 67.5 cm leaving a cavity of 7.5 cm wide between the walls

3)

Wet the walls of the chamber with water

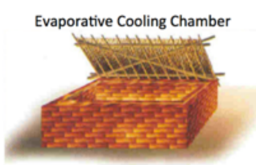
4)

Fill the cavity between the two walls with wet sand. It is better to use the sand from a nearby river if possible.

5)

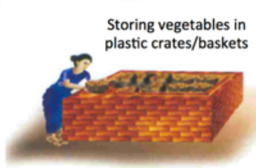
Make a frame from wood the same size as the foundation (165 cm x 115 cm). Cover the wood frame with straw, dry grass, or burlap sack and secure with rope or twine.

6)



The cover goes over the evaporative cooling chamber to keep the cool air inside the chamber

7)

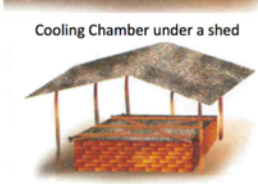


Store your products in plastic crates or baskets in the chamber. Plastic crates containing products must be arranged on top of each other

8)

Place a clear plastic sheet over the plastic baskets containing the fruits and vegetable

9)



ECC in operation to extend the shelf life of fruits and vegetables. If the evaporative cooling chamber is not build in an area that is well shaded, a shed must be constructed to provide shade.

[3] Also commonly called: Zero Energy Cool Chamber (ZECC).

Notes on construction:

- Before you start building your ECC, choose a location:
    - Close to a water source
    - Exposed to wind / breeze
    - If possible a place where there is already shade (this will allow for cost to be saved from making a shed).
- ECC needs to be reinstalled once in 3 years with new bricks and old bricks can be used for other purposes

Tips for improved performance:

- Open the cover as infrequently as possible to keep the cool air in
- Keep the sand between the bricks wet, an irrigation system can ease this process
- Sprinkle water on the cover 1-3 times per day

An evaporative cooling chamber (ECC) under a shade cover made from wood, straw, and plastic

The World Vegetable Center has experimented with constructing ECCs from straw or burlap sacks around the frame of a box made with wooden planks. Research conducted by MIT D-Lab and World Vegetable Center revealed that the performance of these straw and sack ECCs were significantly worse than the brick ECC design described here, and are not recommended. These research results can be found at: http://d-lab.mit.edu/resources/projects/evaporative-cooling.

Construction of Clay Pot Coolers

Clay pot coolers[4] have been used for centuries to help farmers reduce food spoilage and waste, increase their income, and limit the health hazards of spoiled foods. Clay pot coolers are typically used at the household level due to their simple construction and relatively small size. The pot-in-pot design, commonly known as a "Zeer pot," was popularized in 1995 by Mohammed Bah in Nigeria and is composed of two clay pots with the same shape but different sizes. One pot is placed inside the other and the space in between the two containers is filled with sand, which retains the water added. Food is placed inside the interior pot, and both pots are covered with a lid or a damp piece of cloth. Alternative designs exist for clay pot coolers that can include a plastic or metal container inside a single clay pot or dish, or a single clay pot placed in a plastic or metal dish.

Clay pot coolers are typically used at the household level due to their simple construction and relatively small size. The cost of a clay pot cooler can vary significantly based on desired size, design, and local cost of materials. It is important to select an appropriate size according to need to avoid spending more money than is needed.

Merchants selling vegetables in clay pot coolers at a market in Nigeria

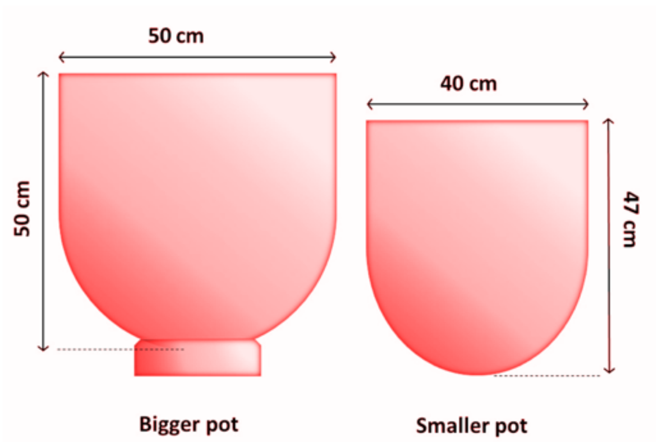
This section provides practical information for constructing clay pot coolers, including:

- Manufacturing of clay pots
- Assembling a clay pot-in-pot cooler
- Alternative clay pot cooler designs

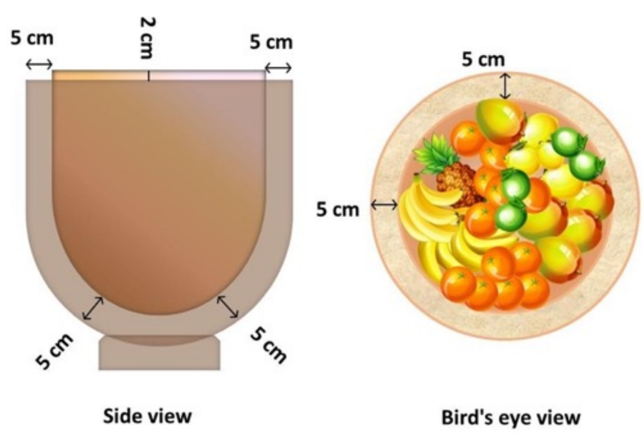
[4] Also commonly called: pot-in-pot refrigerator, Zeer pot, desert fridge, canari frigo, or clay/ceramic refrigerator.

Manufacturing of clay pots

The pot-in-pot configuration requires two fired clay pots of different sizes so that the smaller one can be placed into the larger one (see the figures below). The distance between the two clay pots should be around 3 to 6 cm. Because clay pots with these dimensions are often not found in the normal range of potters' products, they may need to be specially made. Getting the right materials for quality clay pots, forming the pots, and firing them requires expertise and local knowledge. Therefore, it is recommended to produce the clay pots in collaboration with experienced potters.



Dimensions of two ideally sized pots for clay pot coolers.



Dimensions of an assembled clay pot cooler

All stated dimensions in this document are approximate and optimized according to the authors' experience. Nevertheless, these dimensions are only suggestions, and it is not worth the trouble to try to attain them exactly. The most important step is to ensure that the smaller clay pot fits inside the larger one.

If clay pots are already available in the desired shape and design, skip this part of the manual and continue by reading: "Assembling a clay pot-in-pot cooler".

Materials:

Clay is intermingled with broken bits of old clay pots and water into a homogeneous and kneadable substance. Depending on the region, some pot makers add straw or donkey dung to strengthen the stability of the clay pots.

Forming the clay pots:

Forming the clay pots can be simplified by various auxiliary means.

1. Many potters use round concrete molds embedded in the ground and a pestle to beat a clump of clay into a spherical pot. However, a totally spherical shape is not advantageous for a clay pot cooler because the opening would be too small for an adequately sized inner pot. Therefore, when reaching at the widest diameter during creation, it is better to stop beating the clay and continue building up vertically by adding new bulges of clay.
2. Alternatively, different sized basins made of plastic or metal can be used as molds. Take care that the basins have the desired dimensions.
3. Another option is to create a mold made from a mixture of mud, dung, and water. The mold is covered with a small amount of wood chippings to prevent sticking. Contrary to the molds described above, clay is placed regularly on the outside of an upside down mold. The mold should be removed as soon as possible because the shrinkage of drying clay can cause problems.

A woman forming a clay pot in Burkina Faso

Drying:

The clay pots should be completely dried before they are fired. The duration of the drying process is dependent on local weather conditions, but is typically 3 to 7 days.

Dried clay pots ready to be fired

Firing the clay pots:

1. The process of firing pots varies from region to region. Because most potters in developing countries do not have pottery kilns, the firing of the clay pots is performed with large fires in which many clay pots are fired at the same time. (If a pottery kiln is available, it should be used because it is more energy efficient and has a more homogenous heat distribution than open fires.)
2. Various types of wood and dried cow dung can serve as fuel.
3. The fire should be protected from wind. Therefore, it is often placed in a natural or artificial pit and protected by sheet metal on top and pieces of broken clay pots on the sides.
4. After setting the fire, the pots should remain there for around 24 hours before being removed, cooled, and utilized to build clay pot coolers.

A group of potters in front of their pottery kiln

Assembling a clay pot-in-pot cooler

Layer of cement on inner clay pot

The inner (smaller) clay pot can be covered with a thin layer of cement to prevent water diffusing through the pores of the inner clay pot. After applying the layer of cement to the pot, the cement should be sprinkled with water several times in the following 24 hours to facilitate curing. Do not glaze or cover the outer (larger) pot with cement, as this will prevent the necessary evaporation of water and reduce the cooling effect.

Two clay pots ready for installation. The small pot has been covered with a layer of cement.

Sand

The space between the two clay pots should be filled with sieved sand. To achieve optimal functionality, the sand must be processed through two sieves of different mesh sizes. Begin sieving with the larger mesh size to filter out grains and small stones. Next, sieve the sand with a thin cloth to remove dust and tiny clay particles. The remaining coarse sand has a high water storage capacity and does not harden when it dries out like tiny clay particles do. Sieving the sand is important to ensure the long-term functionality of the clay pot cooler.

The sand on the left contains too many tiny clay particles.

Assembly / Installation

1. Place a layer of sand in the bottom of the outer clay pot for the inner pot to sit on. The thickness of this first layer of sand should be adjusted such that the upper rim of the inner pot is at least 2 cm higher than that of the outer pot. This prevents water from entering the inner pot during the daily watering of the sand.
2. Place the inner (smaller) pot inside the outer (larger) pot
3. Fill the space between the two clay pots with sand. During this procedure, ensure that the inner pot stays positioned exactly in the middle of the outer pot so that the distance between the two pots is identical in all directions.
4. Fill the space between the pots with sand to 3 cm below the edge of the outer clay pot.
5. Due to the considerable weight of a completed clay pot cooler, it should be assembled at the desired place of use. This location should be shady, to avoid solar heating, and well ventilated to provide ideal conditions for the evaporation process.

Left: The bottom of the outer pot is filled with sand
Top right: The inner clay pot being placed in the outer pot
Bottom right: The space between the pots filled with sand

Alternative clay pot cooler designs

One adaptation on the common pot-in-pot design is the Janata cooler, developed by the Food & Nutrition Board of India[5]. A plastic or metal storage pot is placed in an earthenware bowl containing sand and water (see the below image in the center). The pot is then covered with a damp cloth that is dipped into the reservoir of water. As water drawn up the cloth evaporates keeping the storage pot cool. The bowl is also placed on wet sand, to isolate the pot from the hot ground.

Another design consists of an earthenware pot in a plastic dish containing sand and water (see the below image on the right). MIT D-Lab and World Vegetable Center researchers observed the usage of clay pot coolers with this configuration in Mali, and included this design in a research study focused on clay pot coolers and evaporative cooling chambers[6].

Left: Diagram of an alternative clay pot cooler design[7]
Center: A clay pot cooler with an earthenware bowl and a plastic storage pot
Right: A clay pot cooler with a plastic bowl and an earthenware storage pot

While the arrangement of the components of the clay pot cooler will impact the performance, the alternative designs described can still provide the key benefits of the most commonly known pot-in-pot configuration (i.e. reduced temperature, increased humidity, protection from animals and insects).

The basic principles of providing a surface and material for water to evaporate to create a cooling effect and the best practices for use (described in the next section) are both applicable for evaporative cooling devices of any configuration.

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[5] Roy, S.K. and Khardi, D.S. (1985). "Zero Energy Cool Chamber". India Agricultural Research Institute: New Delhi, India. Research Bulletin No.43: 23-30.

[6] Verploegen, E.; Sanogo, O.; & Chagomoka, T. (2018) "Evaporative Cooling Technologies for Improved Vegetable Storage in Mali" http://d-lab.mit.edu/resources/projects/evaporative-cooling

[7] *Adapted from Neil Noble, CC BY 4.0, http://answers.practicalaction.org/our-resources/item/evaporative-cooling, Accessed June 1, 2018*

Best Practices for Use

It is important that evaporative cooling technologies are correctly used to ensure maximum cooling performance benefit for the user. Improper use decreases the potential benefits and results in a lower cost-benefit ratio. The tips for appropriate use in the following areas should be considered and followed as much as possible:

- Location
- Watering frequency
- Covering
- Vegetable compatibility
- Hygiene

Location: ECCs and clay pot coolers must be placed in a shady, and well ventilated location. Do not place them in direct sunlight, as the heat from the sunlight absorbed will cancel out the cooling from the increased evaporation rate of water. ECCs may require the construction of a shade cover. Exposure to wind and good ventilation increase the evaporation of water from the surface of the ECC or clay pot cooler. If used in a small room, increased humidity in that room will reduce the cooling effect. Clay pot coolers can be placed on a stand to increase the exposed surface area for evaporation.

Left: A clay pot cooler ready for use
Right: An evaporative cooling chamber (ECC) ready for use

Watering frequency

The watering frequency for clay pot coolers and ECCs depends on the evaporation rate and the device's water storage capacity, which is typically at least once per day. In general, the sand should be kept wet at all times to enable a continuous cooling process. The quantity of water is sufficient when the water does not seep into the sand within a few seconds, which demonstrates that the small spaces between the grains of sand have been filled with water.

Watering a clay pot-in-pot cooler

Left: Watering an evaporative cooling chamber (ECC) by hand
Right: An evaporative cooling chamber (ECC) with an irrigation system for watering

Covering

The opening on top of the ECC or clay pot cooler should be covered with a lid, a plate, or a wet cloth folded several times. Like the sand, the cloth should also be kept wet through the regular addition of water.

Left: Covering a clay pot cooler
Right: Covering an evaporative cooling chamber (ECC)

Vegetable compatibility

Not all produce that can be stored together because some release ethylene, which can accelerate ripening or reduce postharvest quality by promoting senescence, loss of green color, yellowing, change in texture and flavor, formation of necrotic areas on plant tissues, etc. of produce that are sensitive to it. Ethylene is a natural plant hormone produced by some fruits as they ripen, and it is released in the form of a gas.

Fruits or vegetables sensitive to ethylene should not be stored together with produce that are ethylene producers. A full list of produce that are sensitive to ethylene and producers of ethylene are indicated in the section "Guidance on optimal storage conditions for fruits and vegetables". This section should be consulted for best combination of produce to store. Resources for information on vegetable storage compatibility:

- http://postharvest.ucdavis.edu/Commodity_Resources/Storage_Recommendations/Compatibility_Chart_for_Short-term_Transport_or_Storage/
- https://energypedia.info/wiki/Cold_Storage_of_Agricultural_Products#Storage_mix

Hygiene

Like any device for storing food, the ECC or clay pot cooler should be kept clean. The surface of the interior cooling space should be sponged off regularly.

Dissemination

Millions of people in hot, dry regions around the world can benefit from the use of evaporative cooling devices. The following steps are recommended to increase the dissemination of these beneficial technologies:

- Identify and test assumptions with potential end users
- Organize production and distribution
- Raise awareness and increase marketing

If evaporative cooling devices can meet the vegetable cooling and storage needs in a community or region, demand for the production, distribution, and promotion of suitable devices will follow. First, however, the producers and end users of evaporative cooling devices need to be well-trained to understand the usefulness of these technologies for improving vegetable storage along the food supply chain and internalize best practices for their construction and use. Such training will increase the awareness and availability of this technology. These dissemination activities can be carried out by a local business, possibly with the support of a market facilitator, such as a government agency, NGO, or civil society organization.

A woman in Burkina Faso with a clay pot-in-pot cooler for sale

Identify and Test Assumptions with Potential End Users

Conducting a horticulture supply chain analysis at various stages (ranging from the field to the plate) can help to identify specific end-user profiles that could benefit from evaporative cooling technologies in a specific region or community. The goal of such an analysis is to determine the potential need for improved storage among vegetable producers, wholesalers, retailers, end consumers, or other stakeholders.

Once potential end users of ECCs or clay pot coolers have been identified, it is important to consider the suitability of evaporative cooling devices for the specific context of interest (see the "Suitability of Evaporative Cooling Devices" section and the "*Evaporative Cooling Decision Making Tool*").

Underlying assumptions should be checked with potential end users before commencing production and dissemination. Personal exchange is helpful when examining assumed benefits from the perspective of a potential end user, and can uncover hidden cultural or social considerations that may affect the project. An understanding of this context can prevent failure and contribute to the success of dissemination efforts. Some of the key steps for identifying the benefits that evaporative cooling technology can provide to specific user groups include:

- Contact potential end users to interview them about their specific storage needs and how improved vegetable storage could benefit them.
- Test ECCs or clay pot coolers with a small number of potential end users to gain deeper insights into the user experience.
- After interviews and tests are completed, readjust the "need" and "value" factors in the suitability assessment (see the "Suitability of Evaporative Cooling Devices" section).

Left: Interview with Mrs. Setou Mariko, the President of women's group in Bledougou, Sikasso; Right: Group interview with members of a farming cooperative in Bledougou, Sikasso

Organize Production and Distribution

The availability of affordable, high-quality clay pot coolers or ECCs is essential to increasing the adoption of evaporative cooling technology.

Since the production of clay-based earthenware is already common in many regions that could benefit from evaporative cooling devices, the production of clay pots or bricks can be linked with the existing production of clay-based products.

For clay pot coolers, it is important to train potters to produce clay pots with the special characteristics needed for clay pot coolers (see the “Manufacturing of clay pots” section). It is helpful to train potters at their usual workplace, where they have all the raw materials and tools they need, instead of bringing potters together at a “neutral” place and supplying the materials and tools specially.

While the production of the bricks for an ECC does not require specific conditions or skills, it is important to ensure someone familiar with its construction is available at the location where an ECC or clay pot cooler will be installed. Depending on the familiarity of potential end users with evaporative cooling devices, various distribution strategies can be used to obtain and deliver the materials needed for constructing an evaporative cooling device to the end user’s location. Some examples of potential approaches include:

- In regions where evaporative cooling devices are already used and well known it may be sufficient to increase the availability of the key starting products and raw materials.
- In regions where evaporative cooling devices are not yet common, it may be helpful to develop new business models that facilitate some or all of the creation and distribution process. Alternatively, the connection between producers, potential distributors, and end users can be strengthened.
- Another approach is end user training: these users can be trained to make evaporative cooling devices with locally available materials, so they can assemble an ECC or clay pot cooler themselves.
- Any distribution in a region where users are unfamiliar with evaporative cooling technology should be accompanied by information on the proper use of the devices (see the “Best Practices for Use” section).

Production and distribution represent the supply side and are important for the wider dissemination of evaporative cooling devices, but they need to be accompanied by measures for increasing demand, such as raising awareness and marketing.

Raising Awareness and Marketing

The final step in increasing the adoption of evaporative cooling devices is to raise awareness of the technology's benefits, suitability, and use among prospective end users. Some approaches for increasing adoption include:

- **Make the product visible:** Demonstrate a clay pot cooler in locations frequented by the target group. Vegetable markets can be good places to draw the attention of potential users. Due to its size, an ECC would be harder to demonstrate in multiple locations. However, an ECC demonstration device may still be successful when placed at a location with a large number of potential users.
- **Show the benefits and tell a story:** The device's benefits to the target group should be easily understandable. Give examples of how a person has benefited from the use of an evaporative cooling device. For example, describe what changed in a user's life since obtaining the device or how much money the person has saved.
- **Convince through ambassadors:** Identify certain individuals in the target group as ambassadors with a multiplier function. Provide them with evaporative cooling devices. In return, they can act as product ambassadors showcasing its benefits to other potential users.
- **Ensure correct use:** Make sure potential users know how to use a device correctly and ensure they profit from its full range of benefits (see the "Best Practices for Use" section). Incorrect use will decrease the benefits and lower expectations.

Of course, the potential for the proposed approach's success is highly dependent on the local context and specific target group. See the "Suitability of Evaporative Cooling Devices" section to for guidance in determining if evaporative cooling devices and the "*[Evaporative Cooling Decision Making Tool](#)*".

Demonstrating a clay pot cooler to a group of potential users in Tanoussagou, Mali

Conclusions and Additional Resources

This guide presents the most important best practices for clay based evaporative cooling technologies. People in many hot and dry regions of the world could benefit from the use of evaporative cooling devices. Hence, the goal of this document is to provide potential users and disseminators with practical information needed for a wider dissemination of these technologies.

Before starting the production or dissemination, it is advisable to assess the suitability of evaporative cooling devices in a certain context considering the points discussed in the suitability section of this document. If the suitability assessment reveals a promising potential for a specific location, the sections on construction, usage, and dissemination provide practical knowledge from the authors of this guide. The intention of this guide is to bundle the available best practice information on clay pot coolers and evaporative cooling chambers (ECCs) in a way which helps practitioners to contribute to a wider use of evaporative cooling devices. Nevertheless, there are various other sources of knowledge providing knowledge on evaporative cooling devices.

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The information provided in this guide comes mainly from MIT D-Lab's research study in Mali, the clay pot cooler project of Movement e.V. in northern Burkina Faso, and various projects of the World Vegetable Center. For more details, suggestions and ideas for improvements, or possible collaborations contact us via email.

Please let us know if you are starting activities with evaporative cooling devices. This allows us to get an idea about the impact of our efforts for knowledge transfer.

Previous work that provided the basis for this Best Practice Guide

MIT D-Lab's research report on "*Evaporative Cooling Technologies for Improved Vegetable Storage in Mali*" examined users' needs for improved post-harvest vegetable storage, current methods of post-harvest vegetable storage, and the performance of the evaporative cooling devices. Additionally, D-Lab developed an interactive Microsoft Excel-based "*Evaporative Cooling Decision Making Tool*" to help determine if evaporative cooling devices are suitable for a specific context, and to guide the calculation of potential financial savings. These resources are available at: http://d-lab.mit.edu/resources/projects/evaporative-cooling

Movement e.V.'s work with constructing and disseminating clay pot coolers in Burkina Faso: https://movement-verein.org/projekte/tonkrugkuehler/, including information on construction and usage of clay pot coolers in several languages:

- English: Clay pot cooler - Information on construction and usage (PDF)
- French: Canari Frigo - Information on construction and utilization (PDF)
- German: Tonkrugkühler - Construction and use manual (PDF)

The World Vegetable Center's work with constructing and disseminating evaporative cooling chambers in Kenya, Tanzania, and Mali: http://avrdc.org/?s=zecc

Practical Action's resources

- Evaporative cooling overview: https://answers.practicalaction.org/our-resources/item/evaporative-cooling
- Gambia Case study: https://answers.practicalaction.org/our-resources/item/evaporative-cooling-in-gambia
- India Case study: https://answers.practicalaction.org/our-resources/item/evaporative-cooling-in-india
- Research on the performance of clay pot coolers: https://answers.practicalaction.org/our-resources/item/clay-evaporative-coolers-performance-research

Videos for construction and usage of clay pot coolers

- Description of clay pot cooler is and its benefits (Practical Action): https://practicalaction.org/video-zeer-pot-fridge
- Mohamed Bah Abba and the pot-in-pot cooling device in Nigeria (Rolex Awards): http://www.rolexawards.com/profiles/laureates/mohammed_bah_abba
- Desert fridge project (Humanity First and University of The Gambia): http://youtu.be/92fpnUfRt1A
- How to make a Zeer pot for off-grid refrigeration: https://www.youtube.com/watch?v=80aFKtaF_5c
- Clay pot cooler Do-It-Yourself guide (Low-tech lab): https://www.youtube.com/watch?v=7saOOyc5opE

Videos for construction and usage of evaporative cooling chambers

- Build your own Zero Energy Cooling Chamber (ZECC) (World Vegetable Center): https://www.youtube.com/watch?v=enOjVc-kN7Q
- Zero Energy Cooling Chamber (Indian Society of Agribusiness Professionals): https://www.youtube.com/watch?v=C8_D5TI-NoI
- Storage Structure For Fruits Vegetables (Ministry of Food Processing Industries, Government of India): https://www.youtube.com/watch?v=95RRdoySdjA&t=245s

Other information on evaporative cooling technology

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- Appropedia: http://www.appropedia.org/Zeer_pot_refrigeration_%28design%29
- Wikipedia: http://en.wikipedia.org/wiki/Pot-in-pot_refrigerator
- Howtopedia: http://en.howtopedia.org/wiki/How_to_Make_a_Desert_Fridge

Guidance on optimal storage conditions for fruits and vegetables (page 1)

Proper storage conditions are required to maximize storage life and maintain quality of harvested fruits and vegetables.
Fresh fruits need low temperature and high relative humidity to reduce the respiration and slow down the metabolic processes.
The table below indicates optimal temperatures and moisture conditions for some common fruits and vegetables.

Product	Optimal Storage Temperature (°C)	Optimal Humidity (%)	Top Ice Accepted 1)	Water Sprinkle Accepted 2)	Ethylene Production	Sensitive to Ethylene 3)	Approximate Storage Life	Comments
Apples	-1 to 4	90-95	No	No	High	Yes	1-12 months	Chill sensitive stored at 2 to 4 °C
Apricots	-1 to 0	90-95	No	No	High	Yes	1-3 weeks	
Artichokes	0 to 2	90-95	Yes	Yes	No	No		
Artichokes, Jerusalem	-1 to 0	90-95	No	No	No	No	4-5 months	
Asparagus	0 to 2	95-100	No	Yes	No	Yes	2-3 weeks	
Avocados, ripe	3 to 7	85-95	No	No	High	Yes		
Avocados, unripe	7 to 10	85-95	No	No	Low	Yes, Very		Keep away from ethylene producing fruits
Bananas, green	17 to 21	85-95	No	No	Low	Yes		
Bananas, ripe	13 to 16	85-95	No	No	Medium	No		
Basil	11 to 15	90-95	No	Yes	No	Yes		
Beans, dry	4 to 10	40-50					6-10 months	
Beans, green or snap	4 to 7	95					7-10 days	
Beans, sprouts	0	95-100					7-9 days	
Beans. Lima	3 to 5	95					5-7 days	
Beets	0 to 2	90-95	Yes	Yes	No	Yes		
Beets, bunched	0	98-100					10-14 days	
Beets, topped	0	98-100					4-6 months	
Blackberries	0 to 1	90-95	No	No	Very Low	No	2-3 days	
Blueberries	0 to 2	90-95	No	No	Very Low	No		
Bok Choy	0 to 2	90-95	No	Yes	No	Yes		
Broccoli	0	95-100	Yes	Yes	No	Yes	10-14 days	
Brussels Sprouts	0	90-95	Yes	Yes	No	Yes	3-5 weeks	
Bunched Greens	0	90-95	Yes	Yes	No	Yes		Beets, Chard, Green Onions, Parsley, Radish, Spinach
Cabbage, Chinese	0	95-100	No	No	No	Yes	2-3 months	
Cabbage, early	0	98-100	Yes	Yes	No	Yes	3-6 weeks	
Cabbage, late	0	98-100					5-6 months	
Cantaloupe	2 to 3	90-95	No	No	Medium	Yes		
Carrots, bunched	0	95-100	Yes	Yes	No	Yes	2 weeks	Ethylene may cause a bitter flavor
Carrots, immature	0	98-100					4-6 weeks	
Carrots, mature	0	98-100					7-9 months	
Cauliflower	0	95-98					3-4 weeks	
Cauliflower	0 to 2	90-95	No	No	No	Yes		
Celery	0	98-100	Yes	Yes	No	Yes	2-3 months	
Celeriac	0	97-99					6-8 months	
Chard	0	95-100					10-14 days	
Cherries	0 to 2	90-95	No	No	Very Low	No		
Cherries, sour	0	90-95					3-7 days	
Cherries, sweet	-1 to -1	90-95					2-3 weeks	
Chicory	0 to 2	90-95	Yes	Yes	No	No		
Chicory, witloof	0	95-100					2-4 weeks	
Chinese Pea Pods	0 to 2	90-95	No	No	No	No		
Coconuts	13 to 16	80-85	No	No	No	No		Extended storage 0 to 2 °C
Collards	0	95-100					10-14 days	
Corn, sweet	0	95-98	Yes	Yes	No	No	5-8 days	
Cranberries	3 to 6	90-95	Yes	No	No	No		
Cucumbers	10 to 13	95	No	No	Very Low	Yes	10-14 days	
Currants	-1 to 0	90-95					1-4 weeks	
Eggplant	8 to 12	90-95	No	No	No	Yes	1 week	
Elderberries	-1 to 0	90-95					1-2 weeks	
Endive	0	95-100	Yes	Yes	No	No	2-3 weeks	
Escarole	0 to 2	90-95	Yes	Yes	No	No		
Escarole	0	95-100					2-3 weeks	
Figs	0 to 2	90-95	No	No	Low	No		
Garlic	0	65-70	No	No	No	No	6-7 months	May be stored at 13 to 21 °C for shorter periods
Ginger Root	16 to 18	65-70	No	No	No	No		
Gooseberries	-1 to 0	90-95					3-4 weeks	
Grapefruit	13 to 16	90-95	No	No	Very Low	No		
Grapes	-1 to 0	85	No	No	Very Low	Yes	2-8 weeks	
Green Beans	4 to 7	90-95	No	No	No	Yes		
Green Peas	0 to 2	90-95	No	No	No	Yes		
Greens, leafy	0	95-100					10-14 days	
Guavas	7 to 10	90-95	No	No	Medium	Yes		

1) Top icing the products may be very effective keeping the temperature low and the product surface close to 100% humidity.
2) Spraying with water may be effective by keeping the temperature low (evaporative cooling) and the surface 100% humidity.
3) Products sensitive to ethylene should not be stored together with products producing ethylene. Exposure to ethylene may soften the flesh, add bitter taste to the product or/and accelerate ripening.
Data adapted from: https://www.engineeringtoolbox.com/fruits-vegetables-storage-conditions-d_710.html (Accessed May 6th, 2018)

Guidance on optimal storage conditions for fruits and vegetables (page 2)

Proper storage conditions are required to maximize storage life and maintain quality of harvested fruits and vegetables.
Fresh fruits need low temperature and high relative humidity to reduce the respiration and slow down the metabolic processes.
The table below indicates optimal temperatures and moisture conditions for some common fruits and vegetables.

Product	Optimal Storage Temperature (°C)	Optimal Humidity (%)	Top Ice Accepted [1]	Water Sprinkle Accepted [2]	Ethylene Production	Sensitive to Ethylene [3]	Approximate Storage Life	Comments
Herbs	0 to 2	90-95	No	Yes	No	Yes		
Horseradish	-1 to 0	98-100					10-12 months	
Jicama	13 to 18	65-70					1-2 months	
Kale	0	95-100					2-3 weeks	
Kiwi, ripe	0 to 2	90-95	No	No	High	Yes		
Kiwi, unripe	0 to 2	90-95	Ne	No	Low	Yes, Very		
Kohlrabi	0	98-100	Yes	Yes	No	No	2-3 months	
Leeks	0	95-100	Yes	Yes	No	Yes	2-3 months	
Lemons	11 to 13	90-95	No	No	Very Low	No		
Lettuce	0	98-100	No	Yes	No	Yes	2-3 weeks	
Limes	9 to 13	90-95	No	No	Very Low	No		
Lychees	4 to 7	90-95	No	No	Very Low	No		
Mangos	10 to 13	85-95	No	No	Medium	Yes		
Melons, Casaba/Persian	10 to 13	85-95	No	No	Very Low	Yes		Riper melons may be stored at 7 to 10 °C
Melons, Crenshaw	10 to 13	85-95	No	No	Low	Yes		Riper melons may be stored at 7 to 10 °C
Melons, Honey Dew	10 to 13	85-95	No	No	Medium	Yes		Riper melons may be stored at 7 to 10 °C
Mushrooms	0	95	No	Yes	No	Yes	3-4 days	
Napa	0 to 2	90-95	No	No	No	Yes		
Nectarines	-1 to 0	90-95	No	No	High	No	2-4 weeks	
Okra	7 to 10	90-95	No	No	Very Low	Yes	7-10 days	
Onions	0 to 2	65-75	No	No	No	No		May be stored at 13 to 21 °C for shorter periods
Oranges	4 to 7	90-95	No	No	Very Low	No		
Papayas	10 to 13	85-95	No	No	Medium	Yes		
Parsley	0	95-100					2-3 months	
Parsnips	0	98-100	Yes	Yes	No	Yes	4-6 months	
Peaches	-1 to 0	90-95	No	No	High	Yes	2-4 weeks	
Pears	-2 to -1	90-95	No	No	High	Yes	2-7 months	
Peas, green	0	95-98					1-2 weeks	
Peas, southern	4 to 5	95					6-8 days	
Peppers, hot chili	0 to 10	60-70	No	No	No	Yes	6 months	
Peppers, sweet	7 to 13	90-95	No	No	No	No	2-3 weeks	
Persimmons	0 to 2	90-95	No	No	No	Yes, Very		
Pineapples	10 to 13	85-95	No	No	Very Low	No		Odor may influence avacados
Plums	-1 to 0	90-95	No	No	High	Yes	2-5 weeks	
Pomegranates	5 to 10	90-95	No	No	No	No		
Potatoes	7 to 10	90-95	No	No	No	Yes		
Precut Fruit	0 to 2	90-95	No	No	Low	No		
Precut Vegetables	0 to 2	90-95	No	No	No	Yes		
Prunes	-1 to 0	90-95	No	No	High	Yes	2-5 weeks	
Pumpkins	10 to 13	65-70	No	No	No	Yes	2-3 months	
Quinces	-1 to 0	90					2-3 months	
Quinces	0 to 2	90-95	No	No	High	Yes		
Radishes, spring	0	95-100	Yes	Yes	No	Yes	3-4 weeks	
Radishes, winter	0	95-100					2-4 months	
Raspberries	-1 to 0	90-95	No	No	Very Low	No	2-3 days	
Rhubarb	0	95-100	No	Yes	No	No	2-4 weeks	
Rutabagas	0	98-100	Yes	Yes	No	Yes	4-6 months	
Salad Mixes	0 to 2	90-95	No	Yes	No	Yes		
Salsify	0	95-98					2-4 months	
Spinach	0	95-100					10-14 days	
Sprouts	0 to 2	90-95	No	No	No	Yes		
Squashes, summer	5 to 10	95	No	No	No	Yes	1-2 weeks	
Squashes, winter	10	50-70	No	No	No	Yes	1-6 months	
Strawberries	0	90-95	No	No	Very Low	No	3-7 days	
Sweet Potatoes	13 to 16	85-90	No	No	No	Yes	4-7 months	
Tangerines	4 to 7	90-95	No	No	Very Low	No		
Tomatoes, mature green	13 to 21	90-95	No	No	Low	Yes	1-3 weeks	Riping can be delayed by storing at 13 to 16 °C
Tomatoes, ripe	13 to 21	90-95	No	No	Medium	No	4-7 days	
Turnip greens	0	95-100					10-14 days	
Turnips	0	95	Yes	Yes	No	Yes	4-5 months	
Watercress	0	95-100					2-3 weeks	
Watermelon	13 to 21	85-95	No	No	No	Yes, Very		Keep away from ethylene producing fruits

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