Forced-air Evaporative Cooling for Postharvest Fruit and Vegetable Storage
Farmers have a need for improved postharvest fruit and vegetable storage
  – Food spoilage, lower prices at market, time spent transporting produce
Areas for improvement for refrigerated cold rooms:
  – Cost of construction
  – Energy consumption
  – Low humidity
Active evaporative cooling “Swamp coolers”

- Water Distributor
- Evaporative Pad
- Water Reservoir
- Blower

Corrugated cellulose

Aspen pad
Forced-Air Evaporative Cooling Chamber

Concept:

• A used shipping container can be the primary structure
• “Swamp cooler” blows cool air directly through crates
• Rapid cooling of produce
• High humidity environment
Pilot chambers in Kenya and India

Chambers with a storage capacity of 168 crates

- Kenya: Solar-powered off-grid system located at a produce market between Nairobi and Mombasa, cost $15,000 to construct (Solar Freeze)
- India: On-grid system located at a produce market near Bhuj, cost $8,100 to construct (Hunnarshala Foundation)

• An off-grid refrigerated cold room with a similar storage capacity costs between $30,000 and $50,000 to construct
Pilot chambers in Kenya and India

- 6” thick packaged evaporative cooling pads
- 50 mm thick insulation panels
- Galvanized iron support structures
- IoT-connected control system
- 2-tank irrigation system
- 6 separate compartments for crates
- Door system design to minimize air gaps
Pilot chambers in Kenya and India

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Comparison with Refrigerated Cold Rooms

• Energy consumption and cost
  – Forced-air evaporative cooling uses ~ 1/4 the energy of mechanical refrigeration
  – The forced-air evaporative cooling chamber costs less than half of the typical refrigerated cold room

• Cooling rate
  – Forced-air cooling allows for significantly faster cooling rates than room cooling

• Temperature control and minimum temperature
  – The minimum temperature that can be achieved through direct evaporative cooling is limited by the wet-bulb temperature, which is dependent on the ambient air temperature and humidity

• Humidity
  – Evaporative cooling provides a high humidity environment
  – Refrigerated cold rooms typically provide a low humidity environment

• Chamber optimized for inventory management and crop separation
Results from Chamber in India

Percent of produce spoiled after 2 days (chamber operating at 50% capacity factor)

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Control</th>
<th>Chamber</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>50%</td>
<td>17%</td>
<td>33%</td>
</tr>
<tr>
<td>Coriander</td>
<td>70%</td>
<td>20%</td>
<td>50%</td>
</tr>
<tr>
<td>Cucumber</td>
<td>30%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>Cabbage</td>
<td>15%</td>
<td>2%</td>
<td>13%</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>18%</td>
<td>2%</td>
<td>16%</td>
</tr>
<tr>
<td>Eggplant</td>
<td>38%</td>
<td>12%</td>
<td>26%</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>50%</td>
<td>10%</td>
<td>40%</td>
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<tr>
<td>Chili pepper</td>
<td>17%</td>
<td>5%</td>
<td>22%</td>
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<tr>
<td>Ladyfingers</td>
<td>20%</td>
<td>1%</td>
<td>19%</td>
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<tr>
<td>Ridge gourd</td>
<td>30%</td>
<td>8%</td>
<td>22%</td>
</tr>
<tr>
<td>Papaya</td>
<td>24%</td>
<td>8%</td>
<td>16%</td>
</tr>
<tr>
<td>Spinach</td>
<td>60%</td>
<td>20%</td>
<td>40%</td>
</tr>
</tbody>
</table>

Average temperature
- Ambient dry-bulb: 33°C
- In the chamber: 26°C

Average relative humidity
- Ambient: 45%
- In the chamber: 87%
Results from Chamber in Kenya

- Average ambient dry-bulb temperature: 22.6°C
- Maximum ambient dry-bulb temperature: 33.4°C
- Average ambient relative humidity: 56%
- Average ambient wet-bulb temperature: 16.4°C

- Average dry-bulb temperature in the chamber: 17.5°C
- Maximum dry-bulb temperature in the chamber: 21.1°C
- Average humidity inside the chamber: 91%
- Average evaporative cooling efficiency: 82%
Potential Markets

Geography

• Broad Regional Markets:
  – Sub-Saharan Africa
  – India
  – Middle East and North Africa

Application

• Fixed location:
  – Farming cooperatives
  – Produce markets
  – Large producers

• Mobile / seasonal:
  – Moving the container to where the need is greatest

• Pre-cooling:
  – Rapid cooling at the farm gate

• Transportation:
  – Transport from the farm gate to central location
Open-Source Designs

The MIT team published documents covering each of these topics:

1. Introduction
2. Dimensional Design Schematics
3. Airflow System Diagrams
4. Electrical System Diagrams
5. Plumbing System Diagrams
6. Construction Guidelines

- Video overviews for each section of the documentation
- A dedicated website for hosting the documentation

https://www.cooling-chamber.mit.edu/
Next Steps for Forced-Air Evaporative Cooling Chamber

• Test and optimize system performance (ongoing)
  – Pilot chambers in India and Kenya
  – Test chambers at MIT

• Pilot chambers with users in Kenya and India (ongoing)
  – Deployed with farmers and vendors and currently gathering data

• Identify additional partners to replicate the design
  – Cold storage providers
  – Other horticulture value chain stakeholders

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