LOW COST FOOD STORAGE TECHNOLOGY: ENERGY SAVINGS AND PRODUCE STORAGE QUALITY
Outdoor temps in a typical model year for Chicopee

Outdoor Temperature (°F) vs. Hours of the year

- Winter Storage Season
- Median Temp
- Refrigeration Temp range

Seasons:
- Summer
- Winter
Psychrometric temperatures
Humidity Ratio

Humidity Ratio = mass of water vapor / mass of dry air
Relative Humidity

Psychrometric Chart

Relative Humidity

120% RH?

100% RH

50% RH

30% RH
Relative Humidity

The Psychrometric Chart plots curves of constant relative humidity.
Dry Bulb Temperature

The dry bulb temperature can be measured with any common thermometer.
Wet Bulb Temperature
Enthalpy

Energy/Mass of Dry Air = Btu/lb Dry Air
Simplified Psychrometric Chart
ASHRAE Comfort Zone & Veggie Comfort Zone

Humans

Fresh Veg

Dry Bulb Temperature - °F

10% Relative Humidity

30%

40%

50%

60%

70%

80%

90%

100%
PROTOTYPE COOLER
UNIVERSITY OF MASSACHUSETTS
SOUTH DEERFIELD FARM
The Original Cooler

DX Coil Refrigeration

Dimensions: 8’X8’X8’

Insulated Floor 2X4 with ¾” Plywood

4” Foam Panels with Metal Sheathing
Outdoor Air System

- **Guards for Pests and Debris**
- **Intake Fan**
  - 94 Watts
- **Compressor**
  - 547 Watts
- **Exhaust Damper**
- **Insulated Air Intake Duct**
- **Spring Loaded Damper**
Humidification System

Continuous Water Source

HumDisk 10 Centrifugal Humidifier 45 Watts

Dayton Humidistat

Water Feed Housing
Air Circulation

Bathroom Exhaust Fan 37 Watts

Compressor Fan 283 Watts

Duct Releases Air in Opposite Corner
Outoor Air Control Panel

- Hobo Data Logger
- Outdoor Air Control Thermostat Set to 44°F
- Energy Meter
- Fan Speed Controller
Temperature Controls

Compressor Thermostat

Outdoor Fan Thermostat

Cut In

Set Point

Cut Out

˚F

Cut In

Cut Out
Weather for winter storage season (Nov-April) Western Mass.

CHICOPEE_FALLS_WESTO, MASSACHUSETTS, USA

**Weather Hours**
- 22 to 1
- 44 to 23
- 66 to 45
- 88 to 67
- 110 to 89
- 132 to 111
- 154 to 133
- 176 to 155
- 198 to 177

Chart by: HANDS DOWN SOFTWARE, www.handsdownsoftware.com
Weather for winter storage season (Nov-April) Central NH.

Weather Data Location:
CONCORD_MUNICIPAL_ARPT, NEW_HAMPSHIRE, USA

Weather Hours
- 16 to 1
- 32 to 17
- 48 to 33
- 64 to 49
- 80 to 65
- 96 to 81
- 112 to 97
- 128 to 113
- 144 to 129

Chart by: HANDS DOWN SOFTWARE, www.handsdownsoftware.com
Weather for winter storage season (Nov-April) North Central CT.

Weather Data Location:
HARTFORD_BRADLEY_INTL_AP, CONNECTICUT, USA

Weather Hours
- 14 to 1
- 28 to 15
- 42 to 29
- 56 to 43
- 70 to 57
- 84 to 71
- 98 to 85
- 112 to 99
- 126 to 113

Chart by: HANDS-DOWN SOFTWARE, www.handsdownsoftware.com
Conditions in Experimental Cooler and Conventional Cooler

<table>
<thead>
<tr>
<th>outTemp, °F</th>
<th>CoolerTemp, Â°F</th>
<th>SGTemp, °F</th>
<th>CoolerRH, %</th>
<th>SGRH, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Outdoor temp above cutoff

Compressor
Energy Use

- **Outside Air Evap**
  - Fan
  - Circ Fan, Humidifier & Freeze protect

- **Conventional**
  - Fan
  - Compressor
  - Outdoor Fan

KWh/day
Weather for winter storage season (Nov-April) Western Mass.

CHICOPEE_FALLS_WESTO, MASSACHUSETTS, USA

<table>
<thead>
<tr>
<th>Weather Hours</th>
</tr>
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<tbody>
<tr>
<td>22 to 1</td>
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<td>44 to 23</td>
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</tbody>
</table>

Chart by: HANDS DOWN SOFTWARE, www.handsdownsoftware.com
Weather-driven operating hours (for Chicopee, MA)

- Conventional
- Free Cooling
- EvapEnhanced

- Compressor
- Error
- Economizer
Energy usage and operating costs (based on Chicopee, MA weather)

Cost ($)
$400.00
$350.00
$300.00
$250.00
$200.00
$150.00
$100.00

kWh
3000
2500
2000
1500
1000
500
0

Conventional
Free Cooling
EvapEnhanced

Cost
Compressor
Error
Economizer
Cost ($)
First Cost and Simple Payback Period

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Economizer only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humdifier</td>
<td>$900</td>
<td>N/A</td>
</tr>
<tr>
<td>Air intake fan</td>
<td>$200</td>
<td>$200</td>
</tr>
<tr>
<td>Circ. fan</td>
<td>$40</td>
<td>$40</td>
</tr>
<tr>
<td>Misc.</td>
<td>$100</td>
<td>$100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$1,240</strong></td>
<td><strong>$340</strong></td>
</tr>
<tr>
<td><strong>Savings</strong></td>
<td><strong>$213</strong></td>
<td><strong>$122</strong></td>
</tr>
<tr>
<td><strong>Simple Payback</strong></td>
<td><strong>2.91 Years</strong></td>
<td><strong>2.78 Years</strong></td>
</tr>
</tbody>
</table>
Humidifier savings probably bigger at larger scales

- Prototype is only 800 ft$^3$
- Identical setup can work up to 12,000 ft$^3$
- Humidisk10 can work up to 20,000 ft$^3$ at 1 ACH.
- 70 CFM Circ fans will have to be multiplied (approx. 1 for every 1000 ft$^3$.)
DX Cooling Process

Coil Temp
Vapor Profile of a Carrot in Storage

Vapor Pressure: 0.689 kPa
35°F, Saturated

H₂O

Vapor Pressure: 0.414 kPa
35°F, 60% RH
Vapor Profile of a Carrot in Storage

Vapor Pressure: 0.689 kPa
35°F, Saturated

Vapor Pressure: 0.662 kPa
35°F, 96% RH
Vapor Profile of Carrot in Storage in Winter

Vapor Pressure: 0.689 kPa
35°F, Saturated H₂O

Vapor Pressure: 0.662 kPa
35°F, 96% RH

Vapor Pressure: 0.191 kPa
20°F, 50% RH
0.00193 lbs
H2O/lb dry air
condensed
Vapor Pressure: 0.689 kPa
35°F, Saturated

Vapor Pressure: 0.662 kPa
35°F, 96% RH

Vapor Pressure: 2.339 kPa
89°F, 50% RH
Cooling Process

0.00446 lbs H2O / lb dry air
Condensed
20°F outside
60°F outside
90°F outside
Construction Elements

• Lots of insulation (R-20 min) on all sides including floor.
• Interior materials must be corrosion and rot resistant (metal, plastic, cement)
• Vapor barrier on interior (metal and plastic)
• Minimum 2/3 of total R value must be air impermeable and vapor retardant (foam board with sealed seams) interior of sheathing.
• Air tight construction. Test by pressurizing with fan and use theatrical fog or a moistened back of the hand.
Mechanical Elements

• circulation *independent* of compressor
• *controlled* fresh air exchanges
• *Atomizing* humidification system controlled by *humidistat*
• Temperature controlled by *accurate* thermostats
• Set points based on *local* weather characteristics
• Monitor with humidity and temperature sensors (data logging is preferable, but thermometer hygrometers are okay)
From Season extension to System extension?

- Short term market crop storage (e.g. tomatoes, greens, lettuce, etc.)
- Staged field heat reduction
- Any suggestions?
Questions?

• Thanks!
  – USDA
  – Ruth Hazzard
  – Daniel Pepin
  – Amanda Brown
  – Simple Gifts Farm