

**LOW COST FOOD STORAGE
TECHNOLOGY: ENERGY
SAVINGS AND PRODUCE
STORAGE QUALITY**

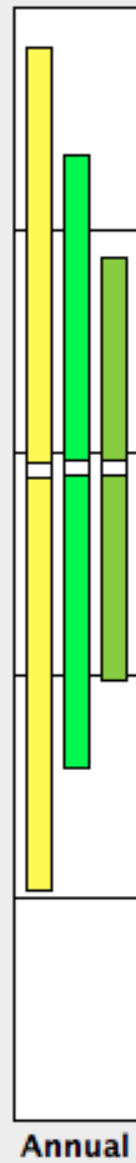
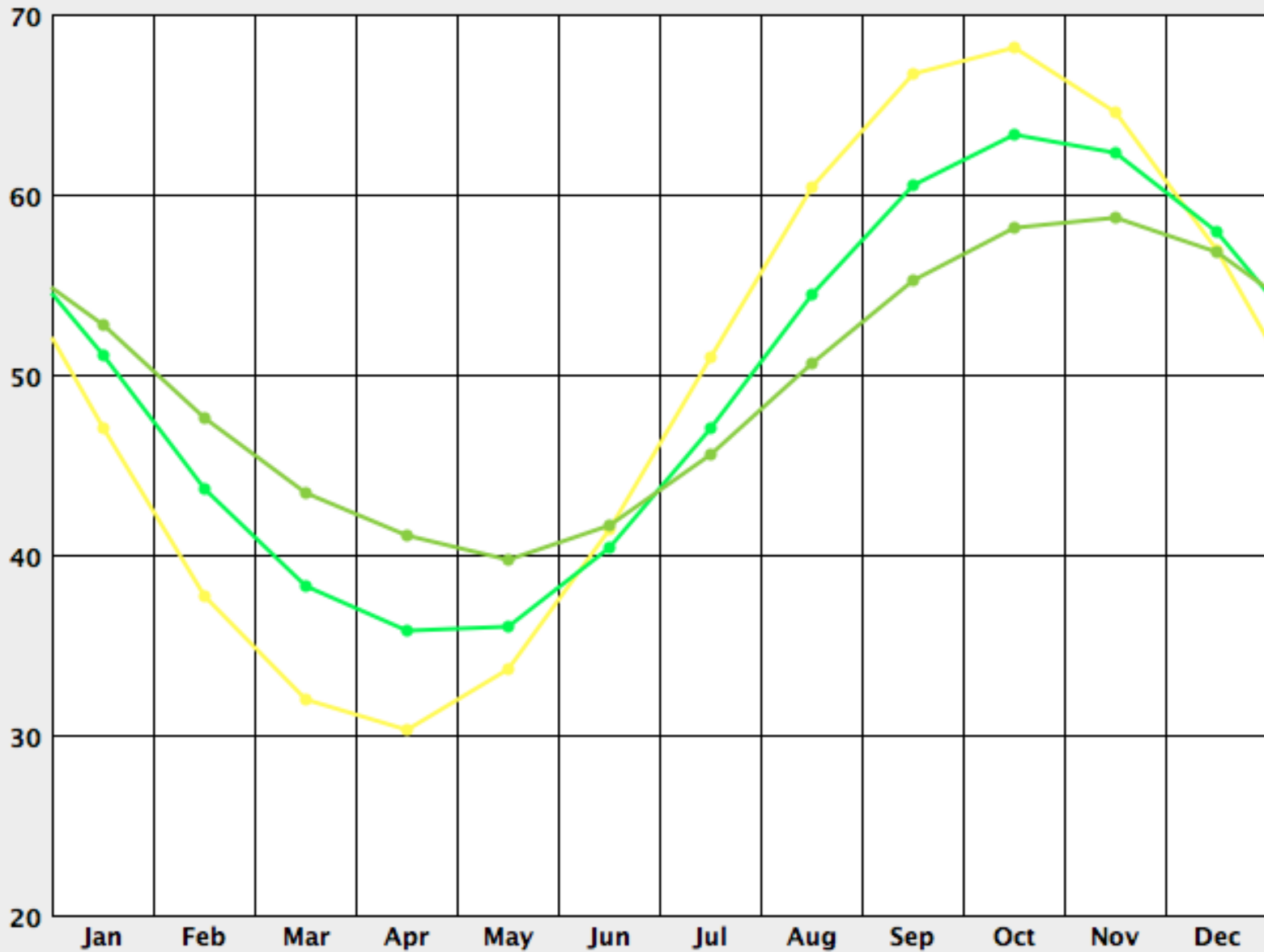
Ben Weil
Luke Doody
University of
Massachusetts
Amherst

Traditional Root Cellar



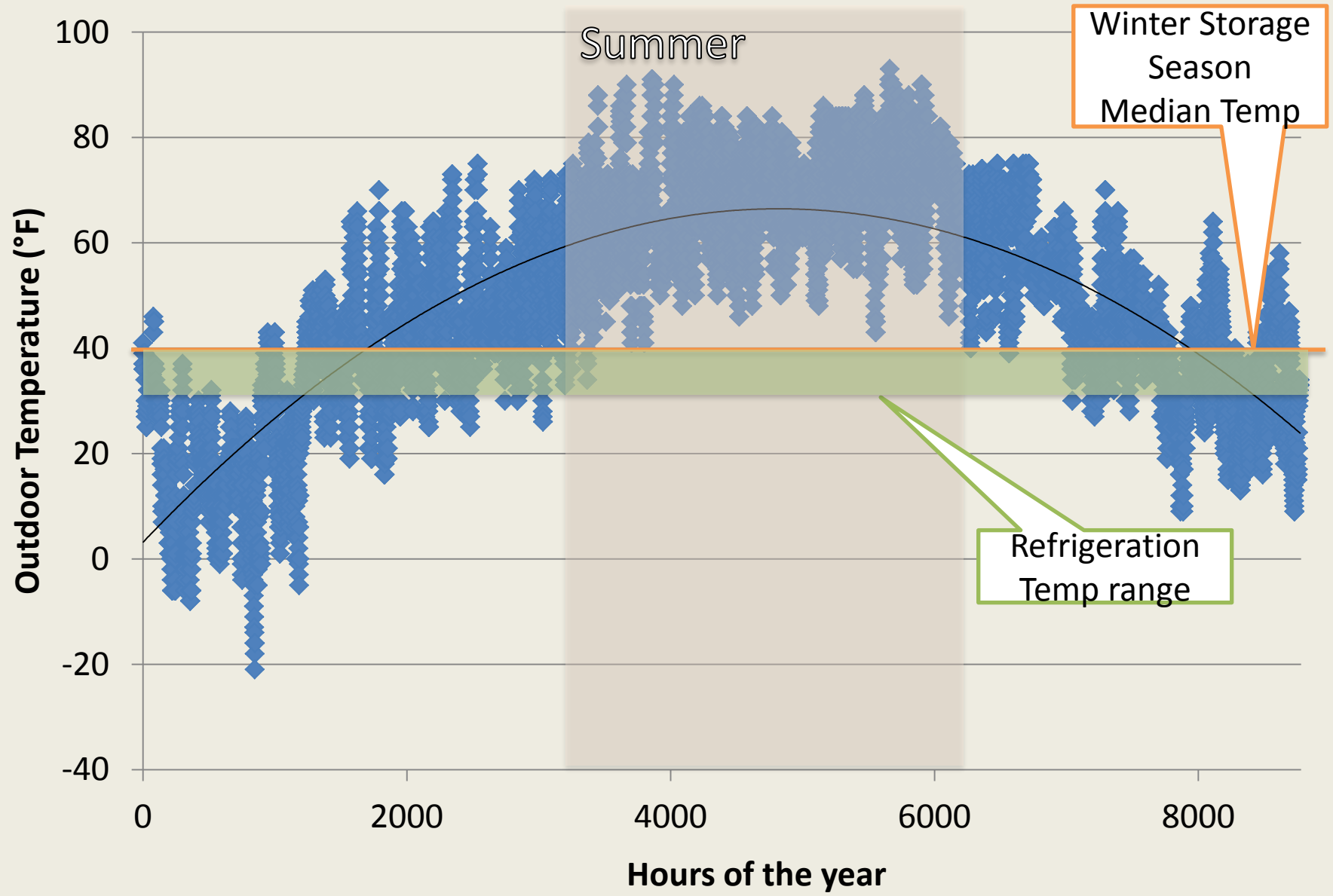
Department of the Interior. Bureau of Reclamation. Civilian Conservation Corps Division. 1940

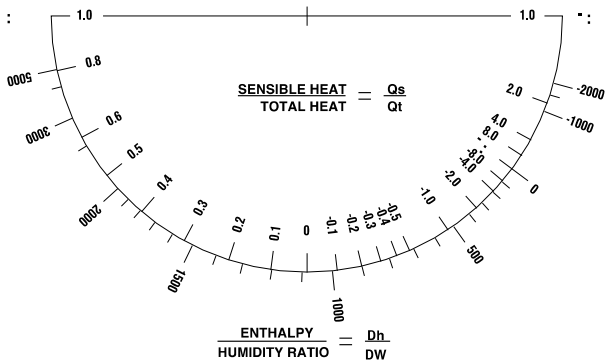






Outdoor temps in a typical model year for Chicopee



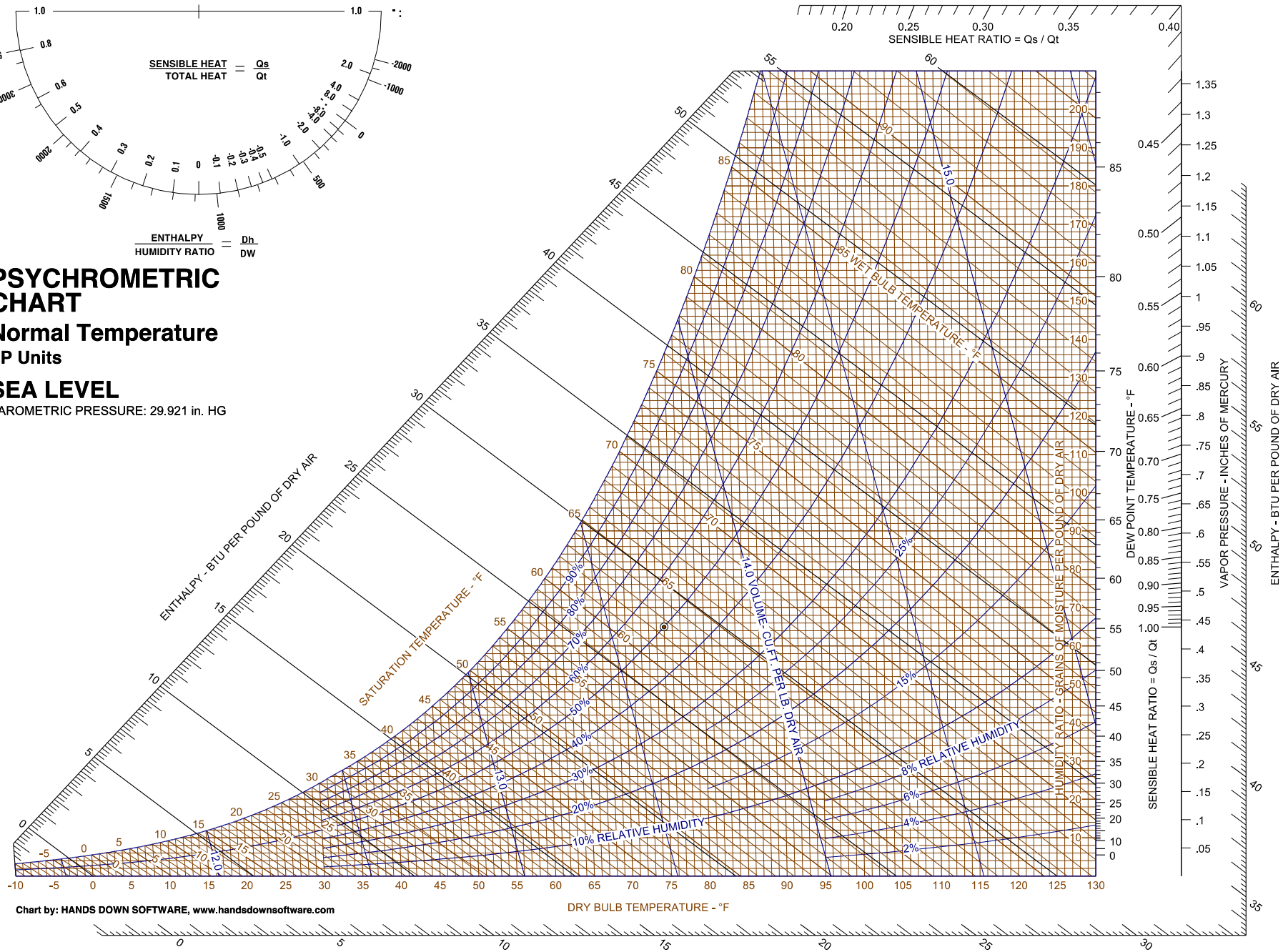


PSYCHROMETRIC CHART

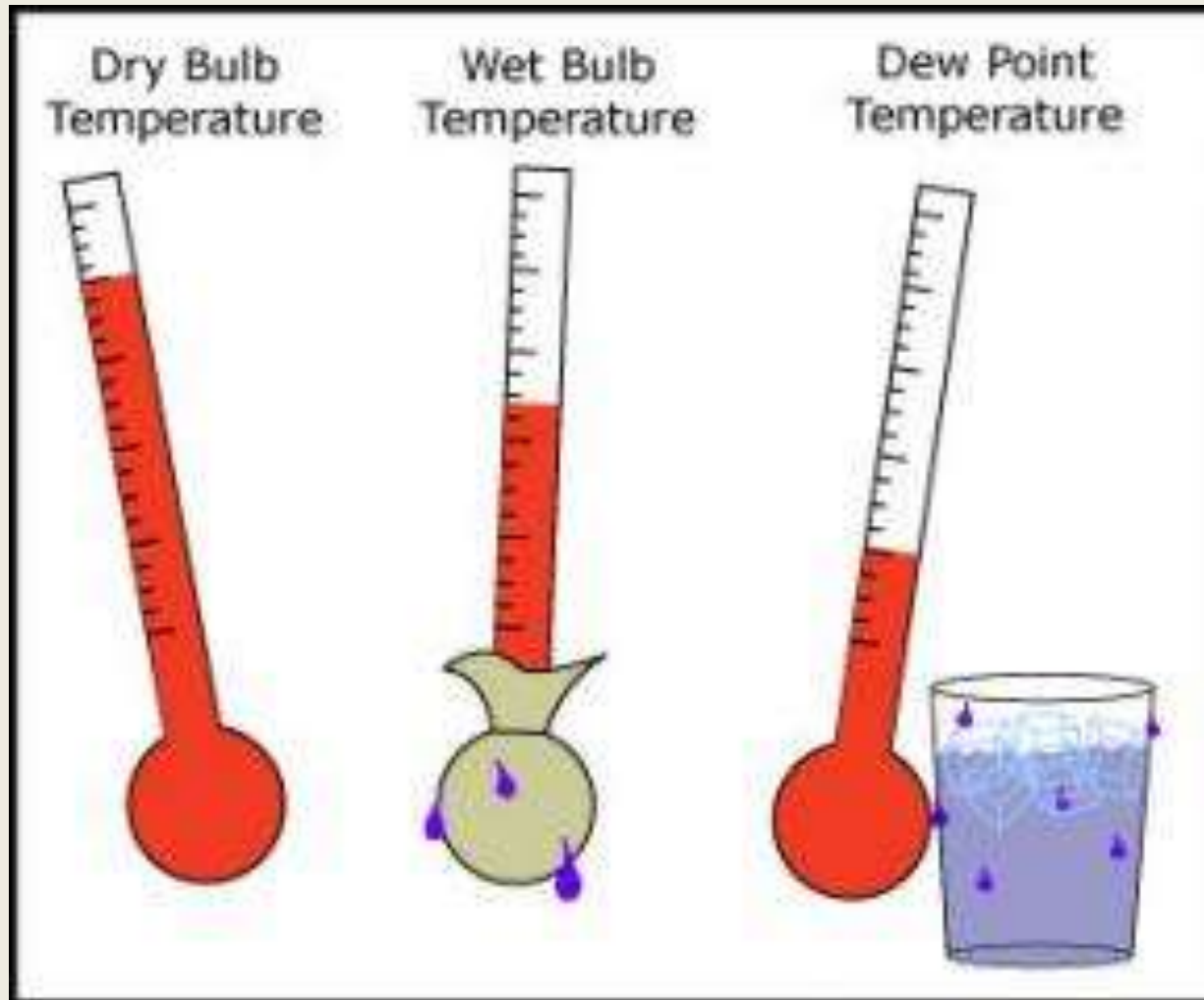
Normal Temperature
I-P Units

SEA LEVEL

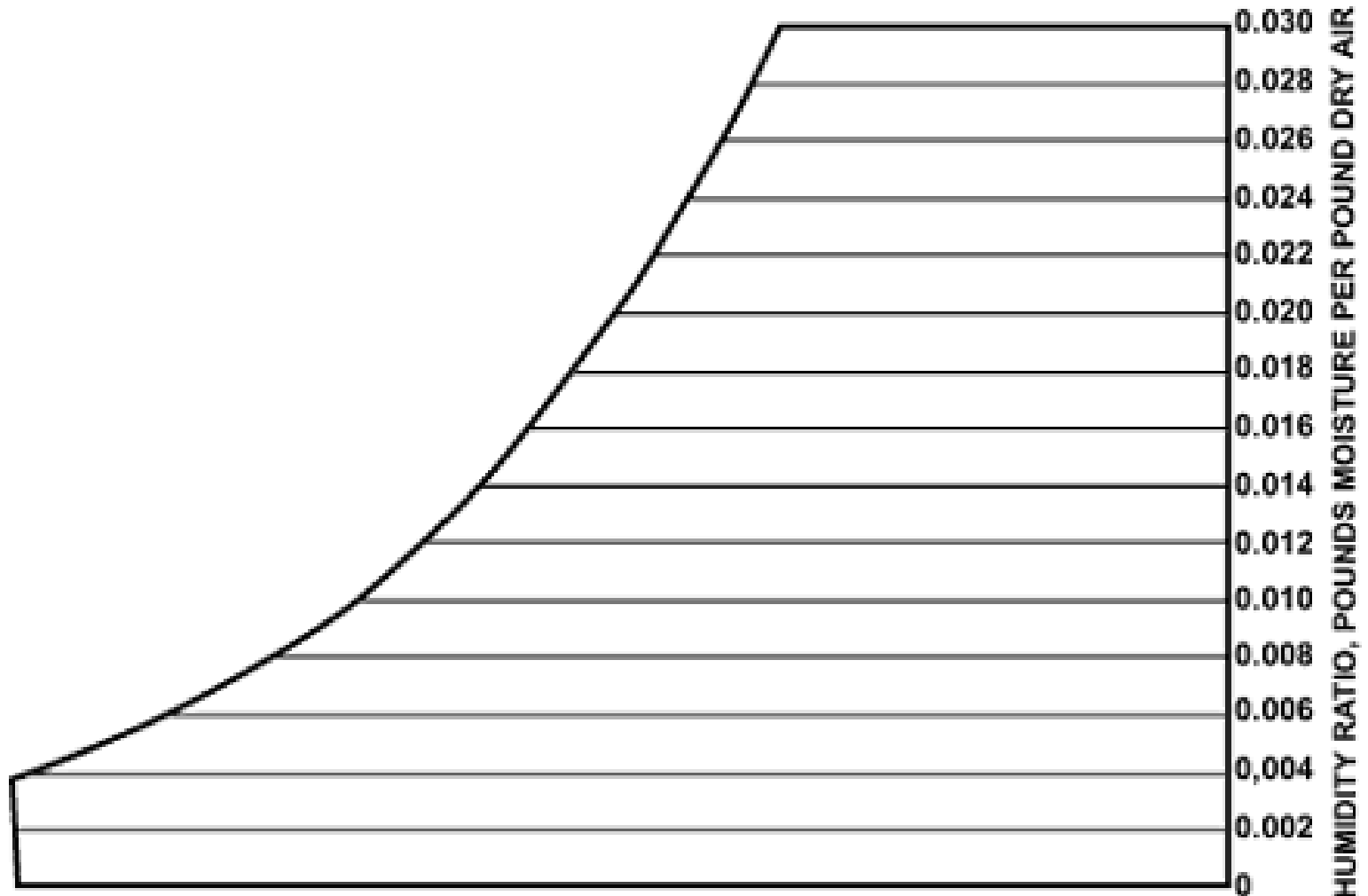
BAROMETRIC PRESSURE: 29.921 in. HG



Psychrometric temperatures



Humidity Ratio

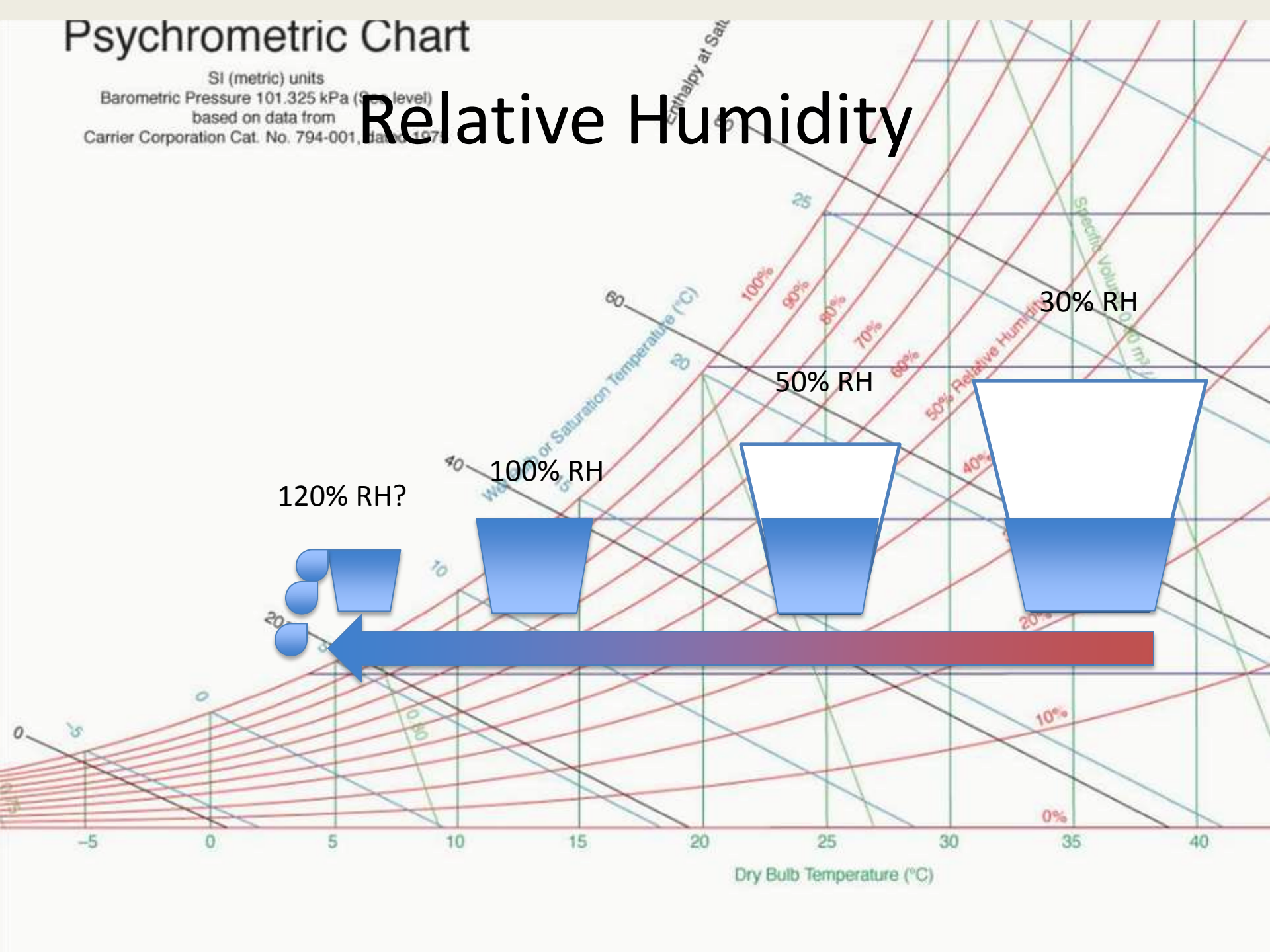


Humidity Ratio = mass of water vapor / mass of dry air

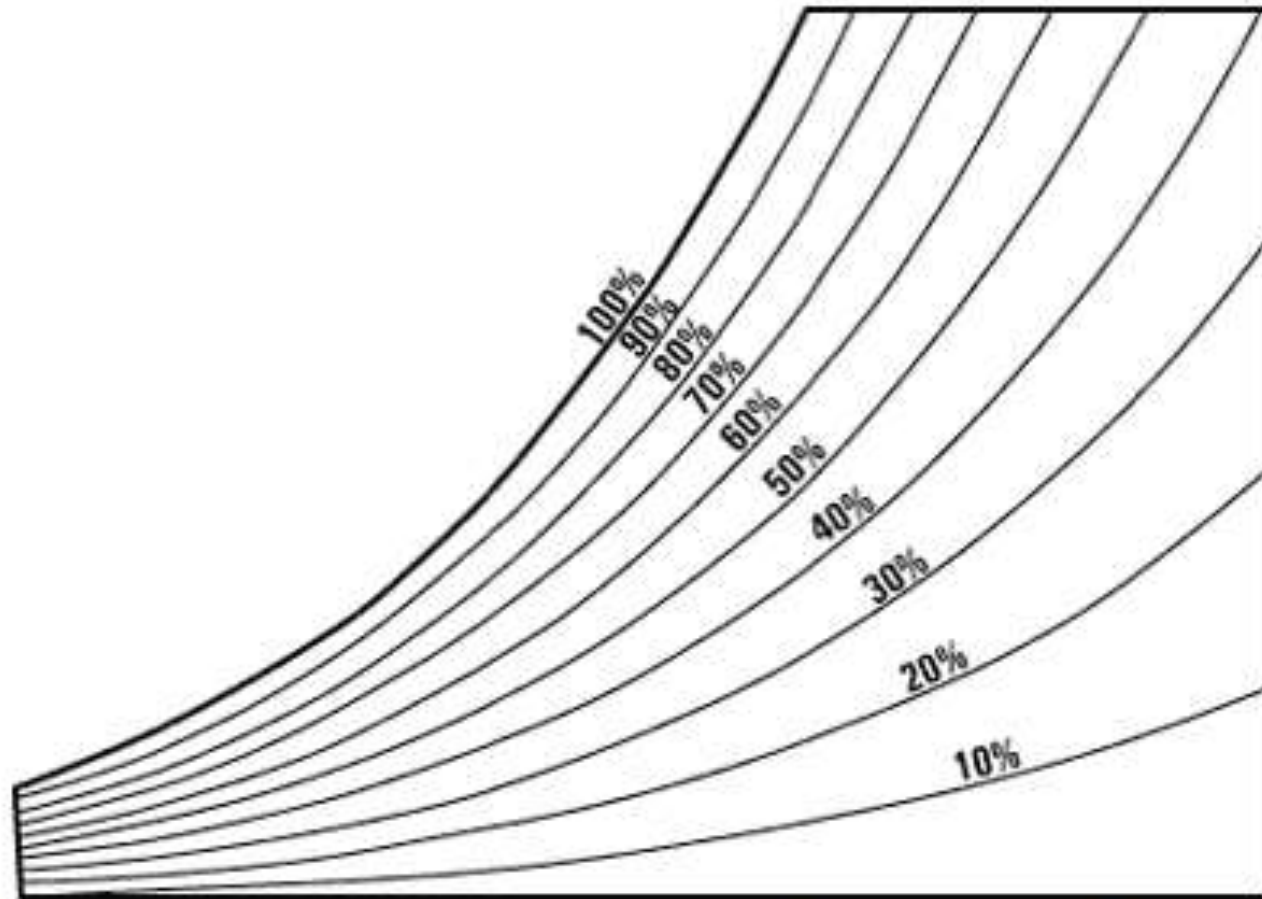
Psychrometric Chart

SI (metric) units
Barometric Pressure 101.325 kPa (Sea level)
based on data from
Carrier Corporation Cat. No. 794-001, June, 1977

Relative Humidity

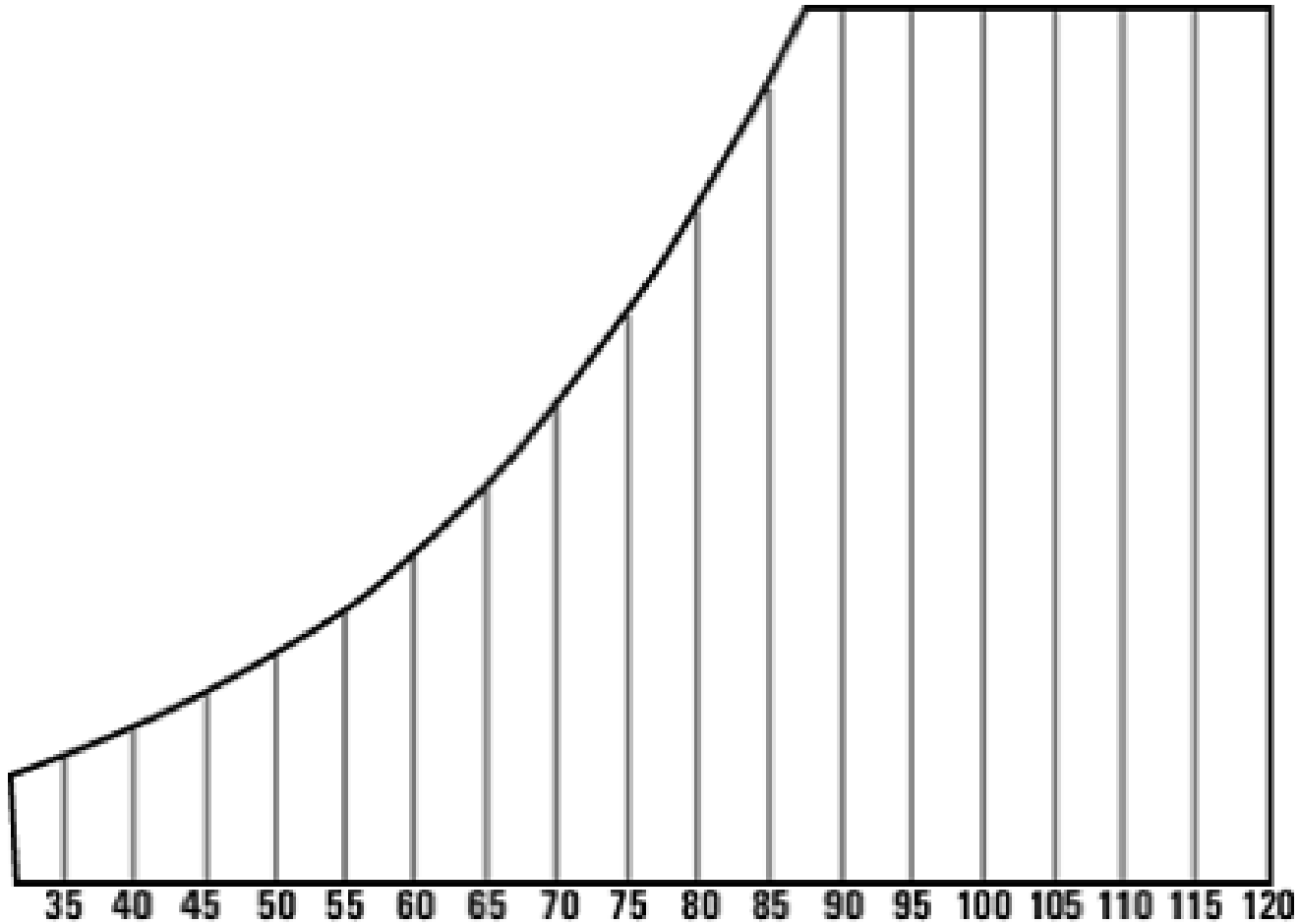


Relative Humidity



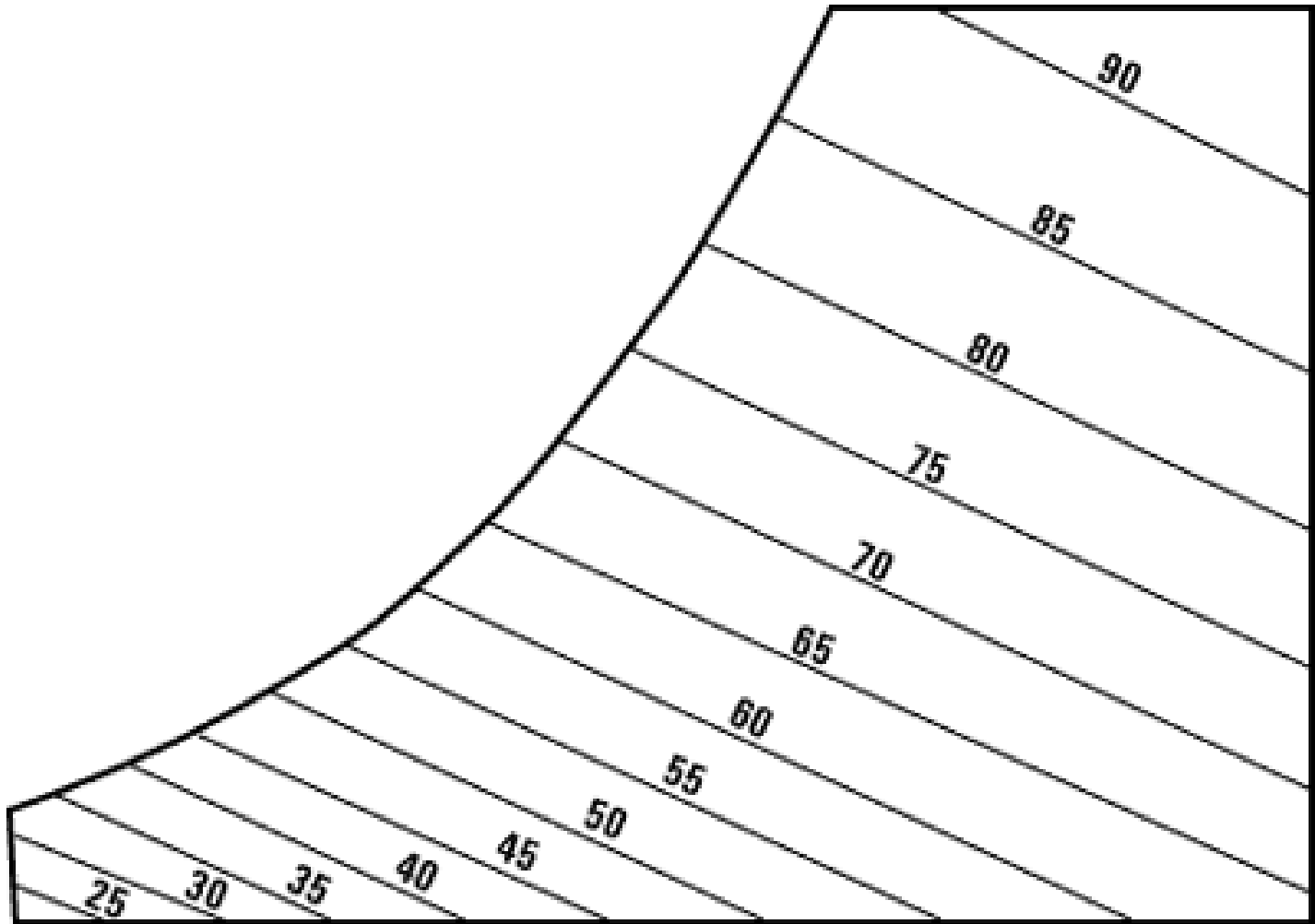
The Psychrometric Chart plots curves of constant relative humidity.

Dry Bulb Temperature

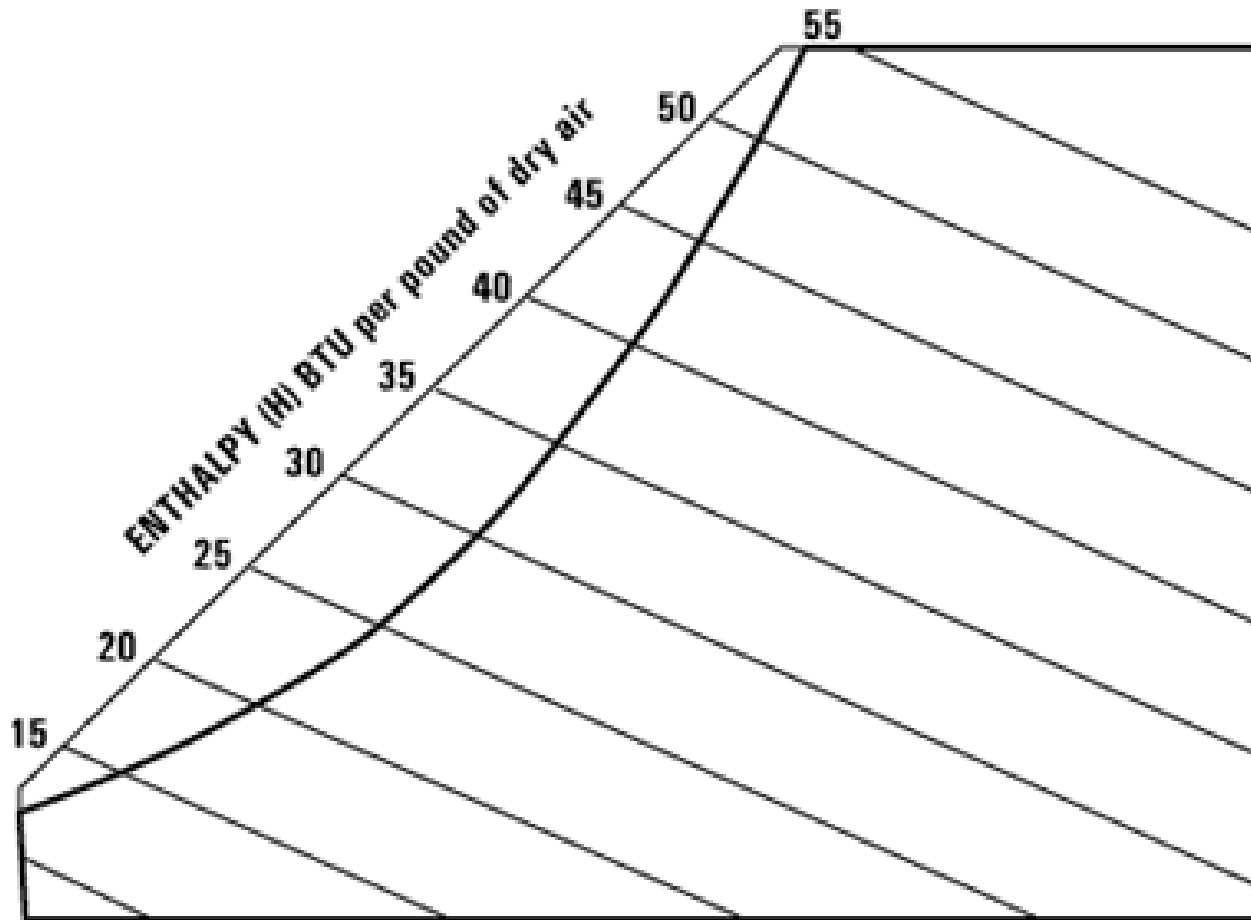


The dry bulb temperature can be measured with any common thermometer.

Wet Bulb Temperature

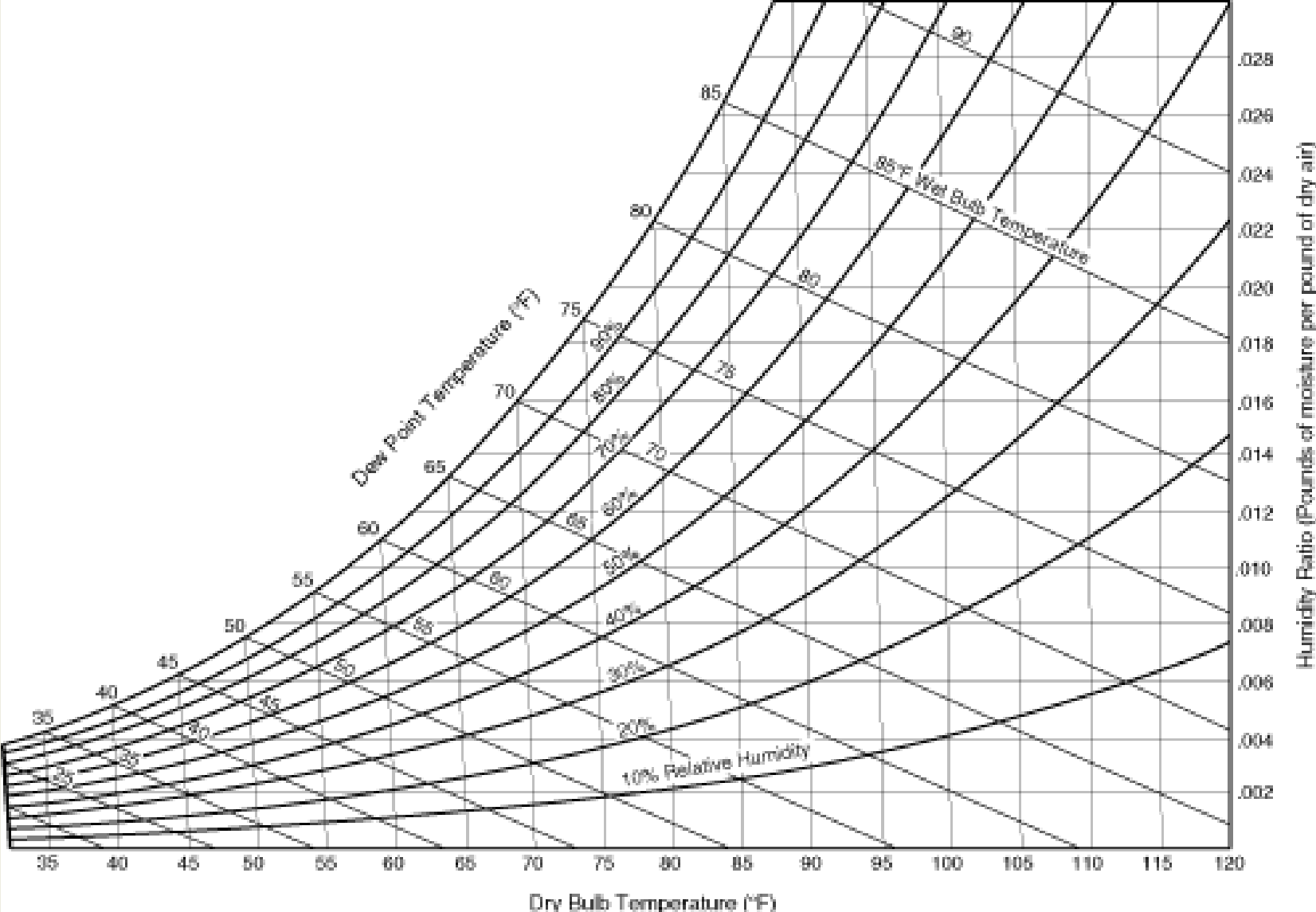


Enthalpy

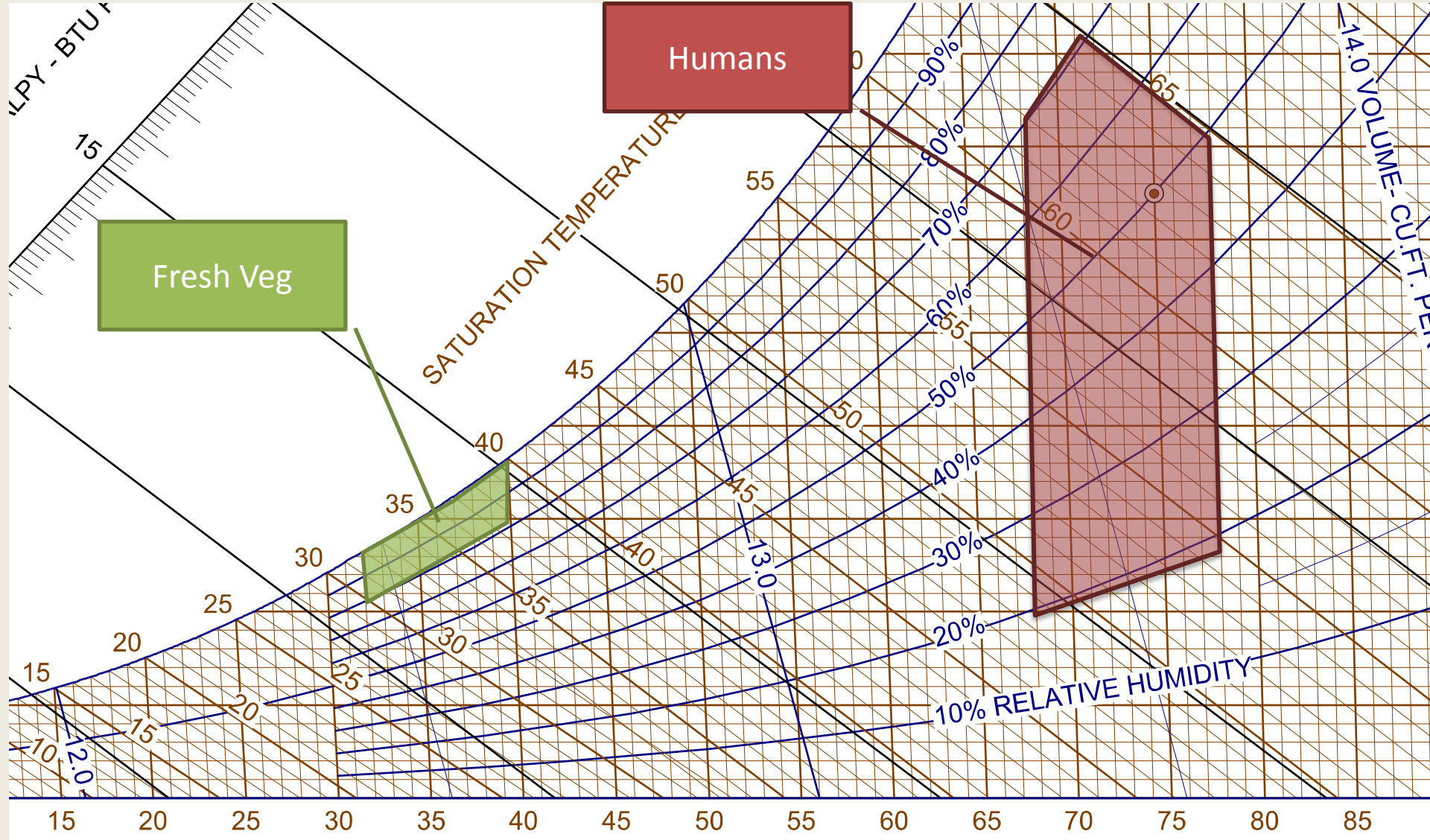


Energy/Mass of Dry Air = Btu/lb Dry Air

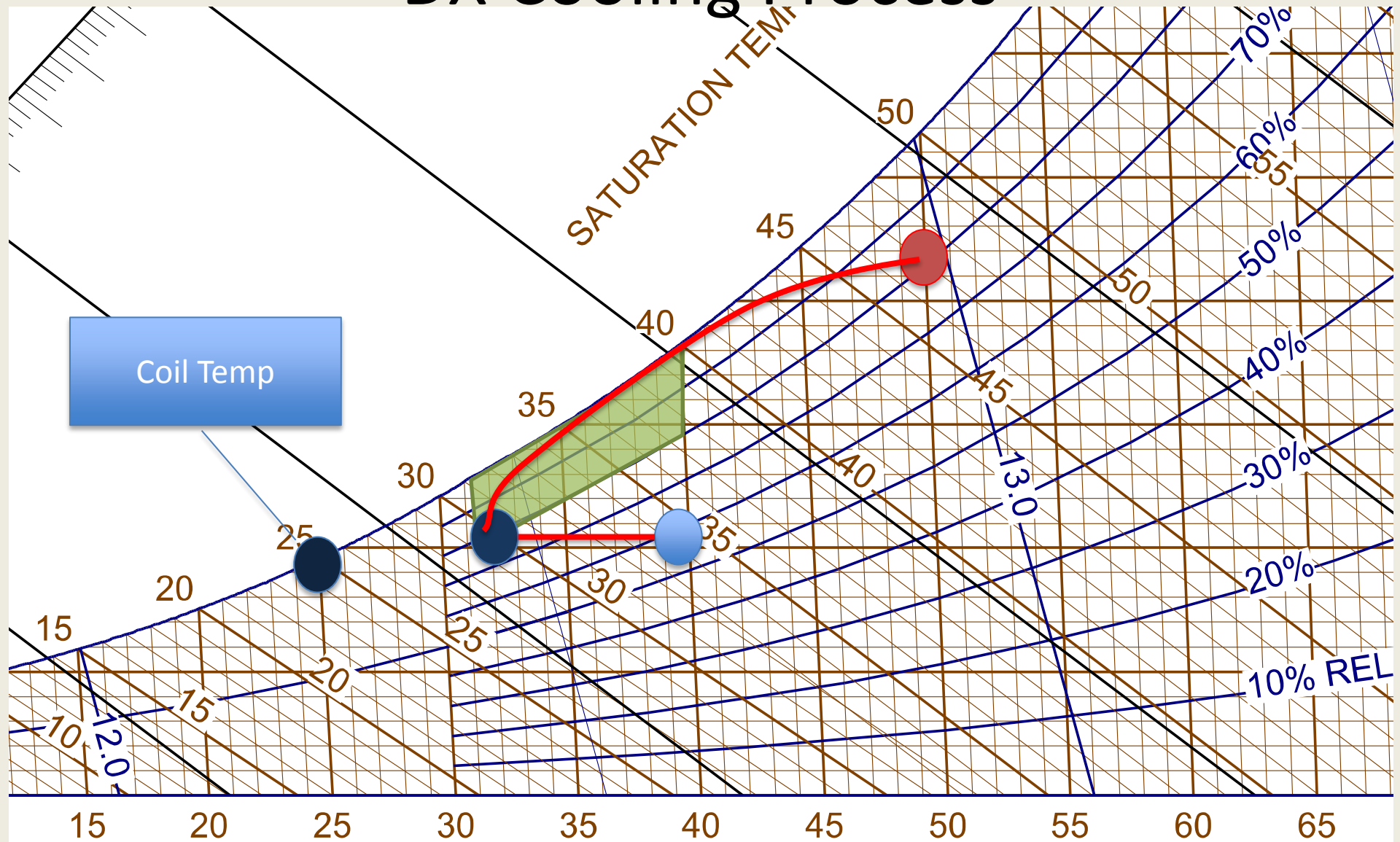
Simplified Psychrometric Chart



ASHRAE Comfort Zone & Veggie Comfort Zone



DX Cooling Process



Coil Temp

PROTOTYPE COOLER

UNIVERSITY OF MASSACHUSETTS

SOUTH DEERFIELD FARM



The Original Cooler

DX Coil
Refrigeration

Dimensions:
8'X8'X8'



4" Foam Panels
with Metal
Sheathing

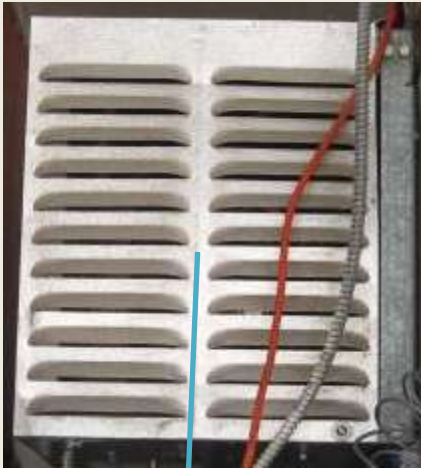
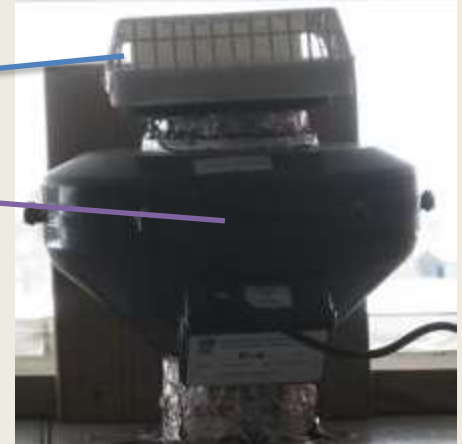
Insulated Floor
2X4 with $\frac{3}{4}$ "
Plywood

Outdoor Air System

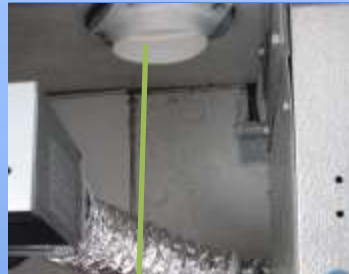
Guards for
Pests and
Debris



Intake Fan
94 Watts



Compressor
547 Watts



Exhaust
Damper

Insulated Air
Intake Duct



Spring
Loaded
Damper

02/10/2014

Humidification System

Continuous
Water Source



Water Feed Housing

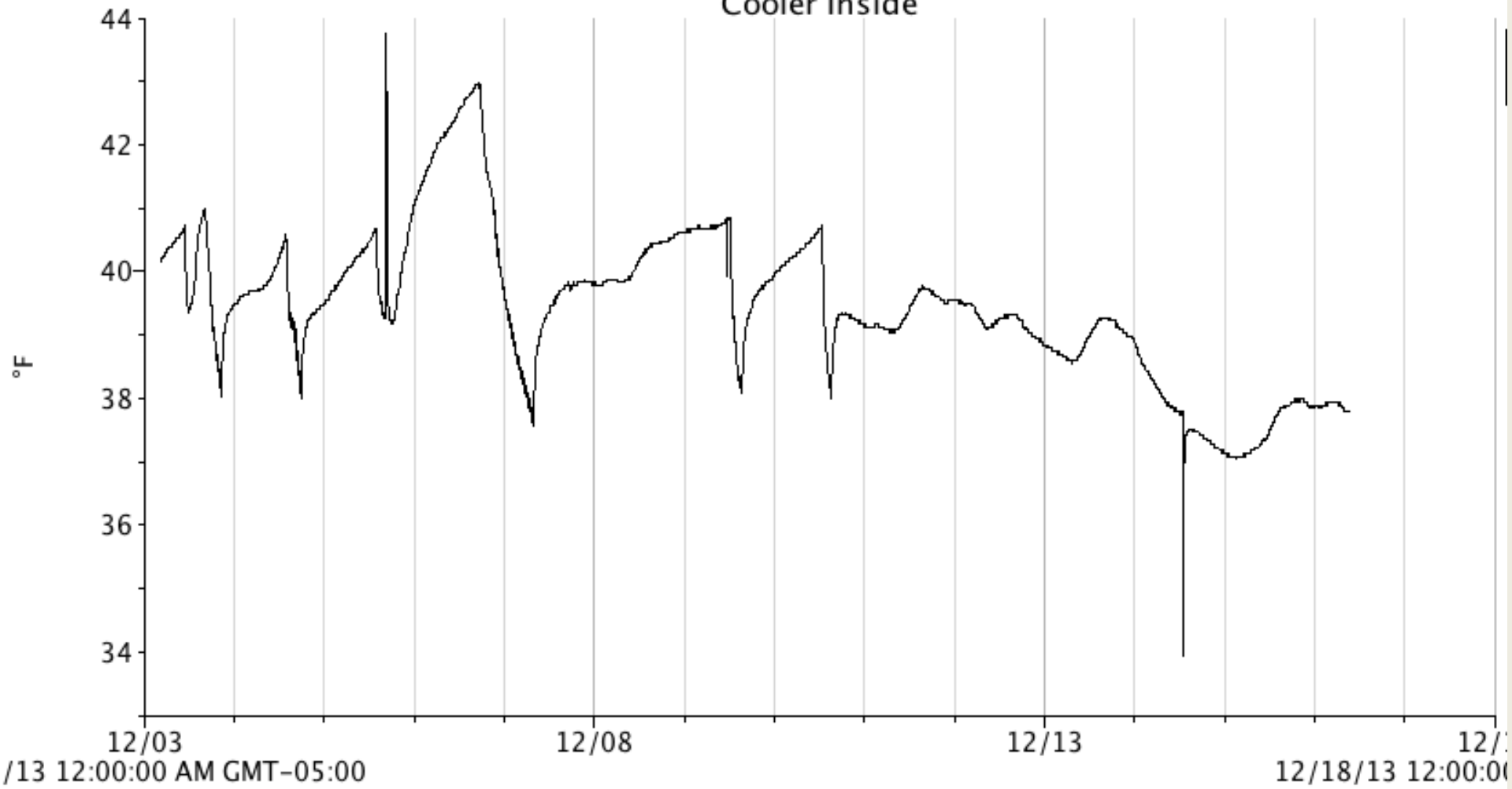
HumDisk 10
Centrifugal
Humidifier
45 Watts



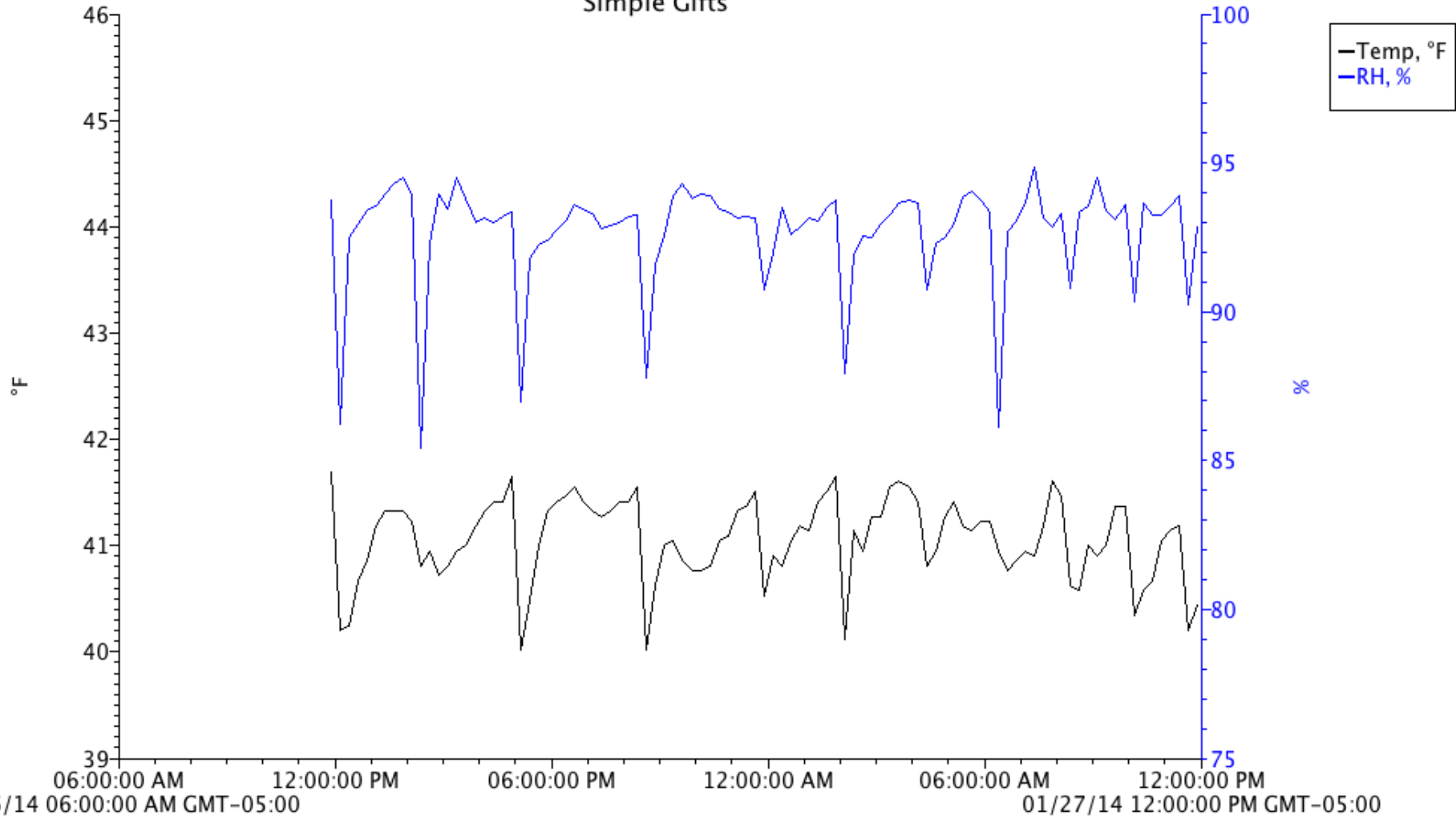
Dayton
Humidistat



Cooler Inside



Simple Gifts



Air Circulation



Bathroom Exhaust Fan **37**
Watts



Compressor Fan
283 Watts

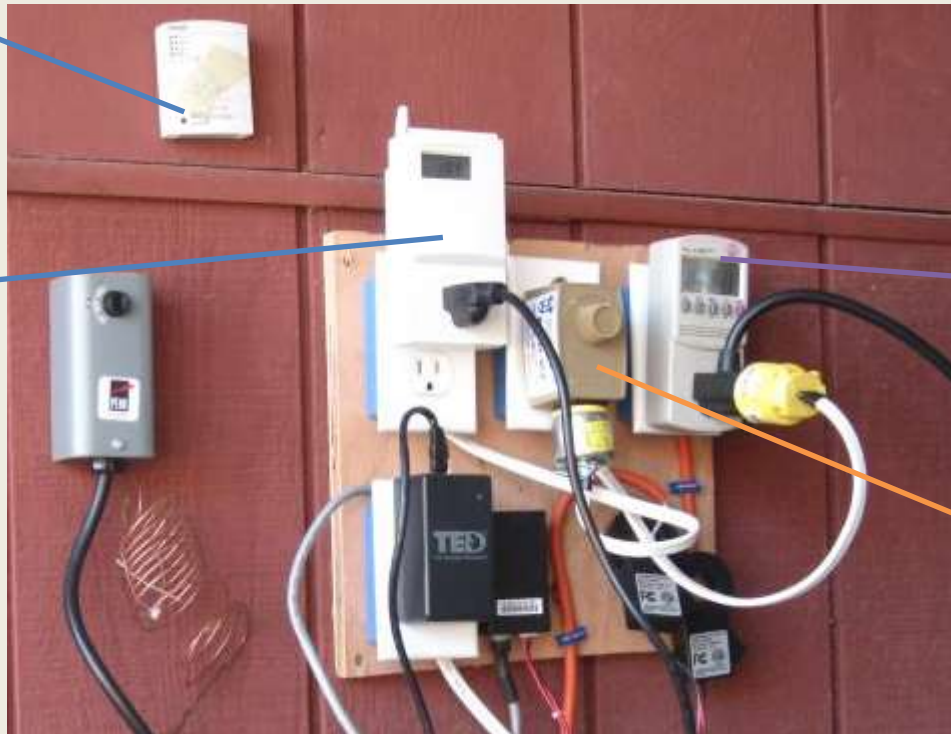


Duct
Releases Air
in Opposite
Corner

Outdoor Air Control Panel

Hobo Data
Logger

Outdoor Air
Control
Thermostat
Set to 44°F



Energy Meter

Fan Speed
Controller

Temperature Controls

Compressor
Thermostat

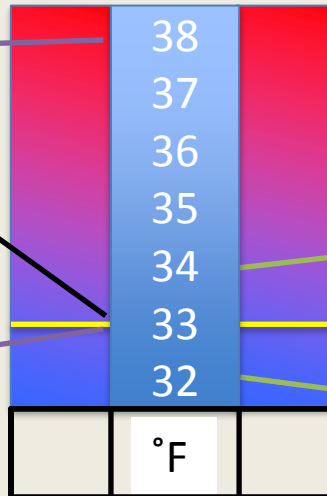


Outdoor Fan
Thermostat

Cut In

Set Point

Cut Out



Cut In

Cut Out

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

CHICOPEE_FALLS_WESTO, MASSACHUSETTS, USA

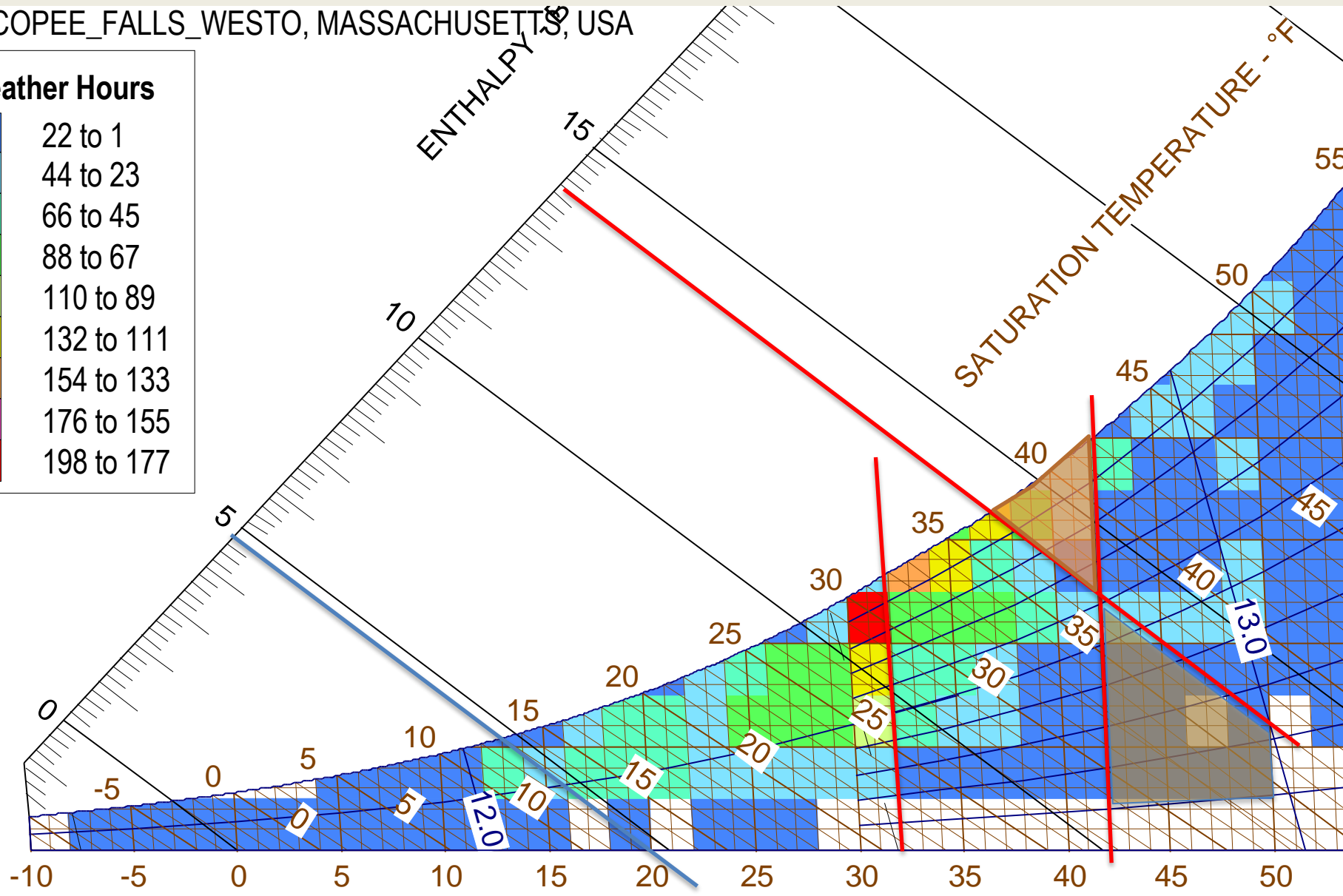
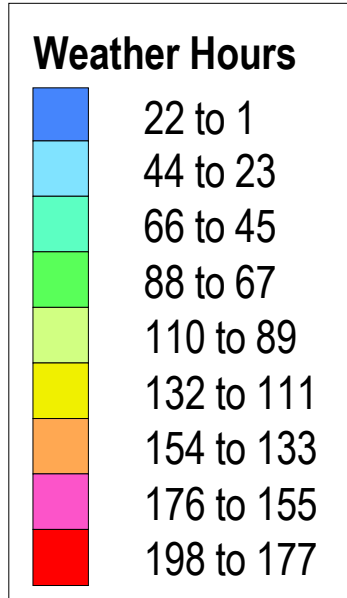


Chart by: **HANDS DOWN SOFTWARE**, www.handsdownsoftware.com

Weather for winter storage season (Nov-April) Central NH.

Weather Data Location:
CONCORD_MUNICIPAL_ARPT, NEW_HAMPSHIRE, USA

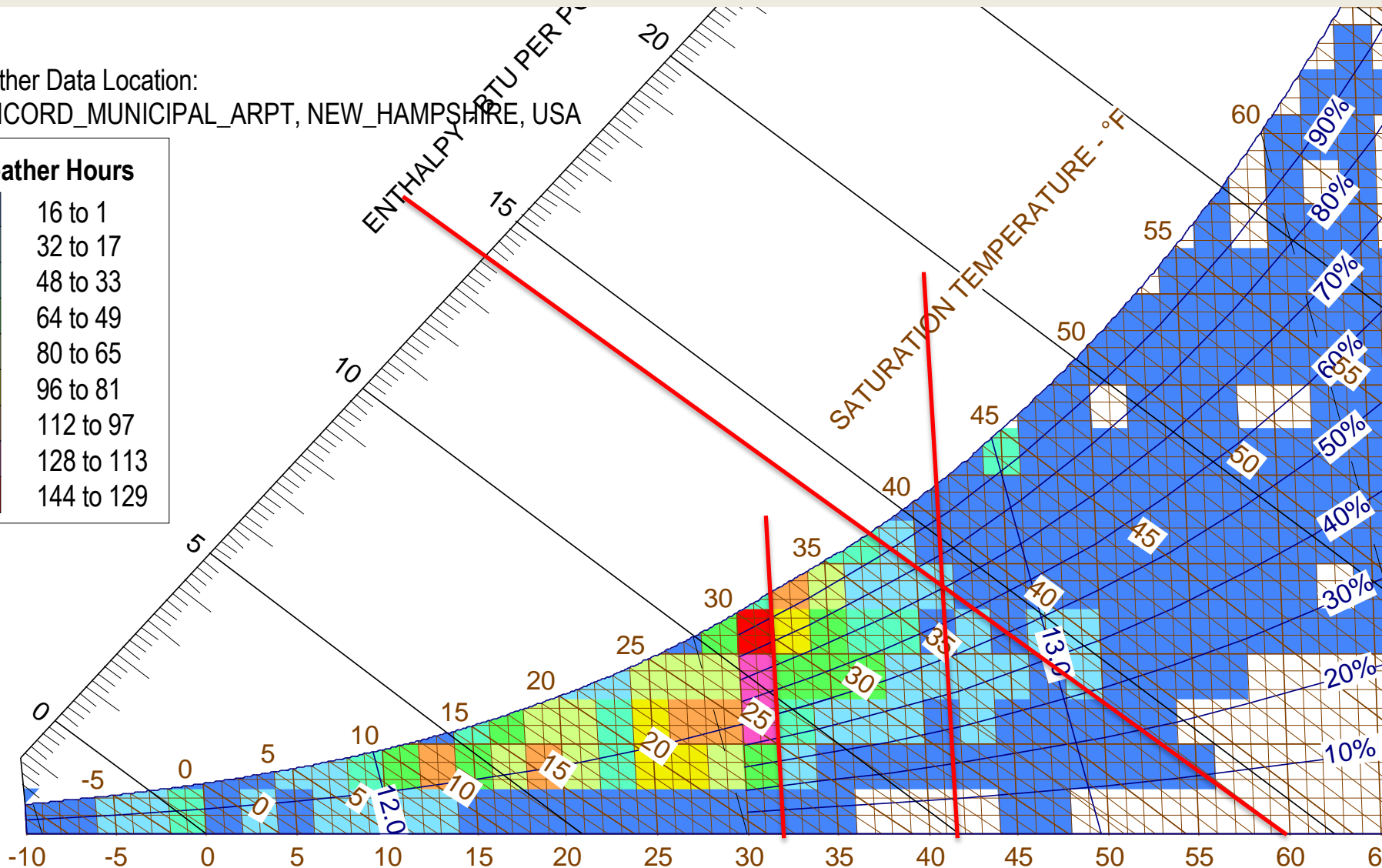
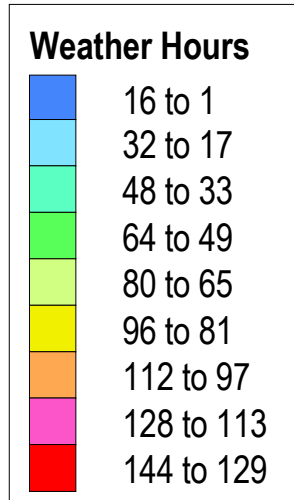
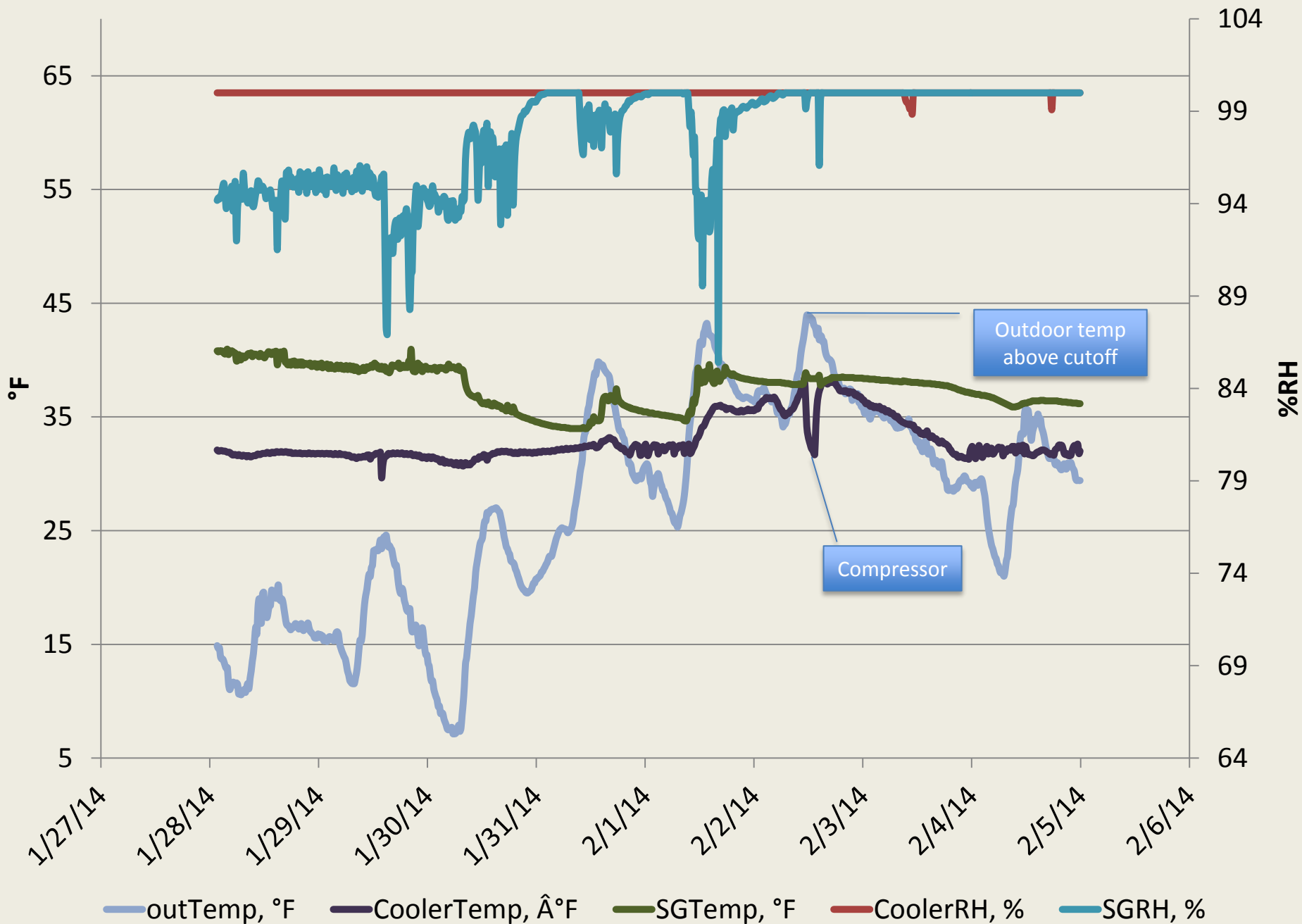


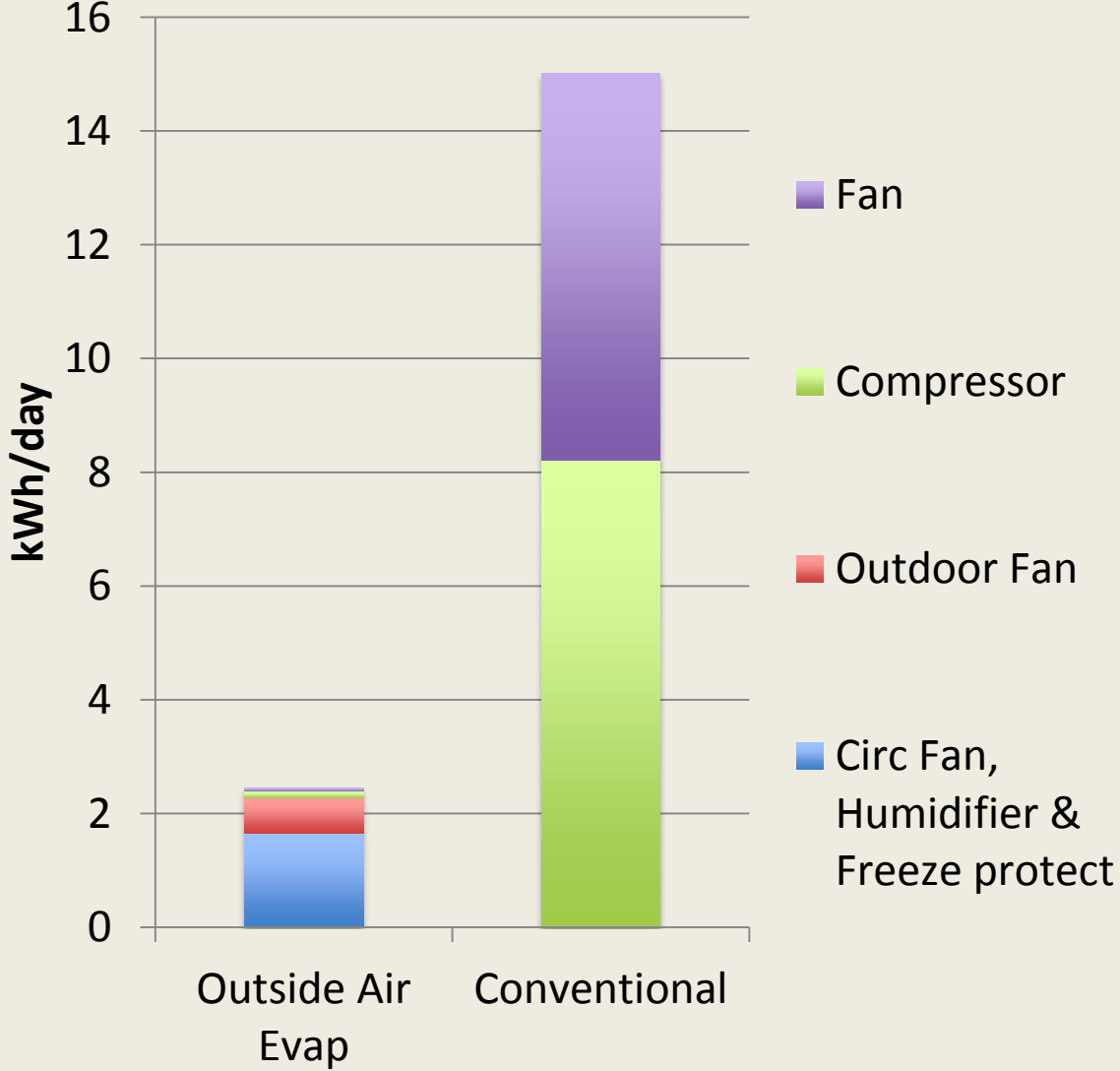
Chart by: **HANDS DOWN SOFTWARE**, www.handsdownsoftware.com

DRY

Conditions in Experimental Cooler and Conventional Cooler



Energy Use



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

CHICOPEE_FALLS_WESTO, MASSACHUSETTS, USA

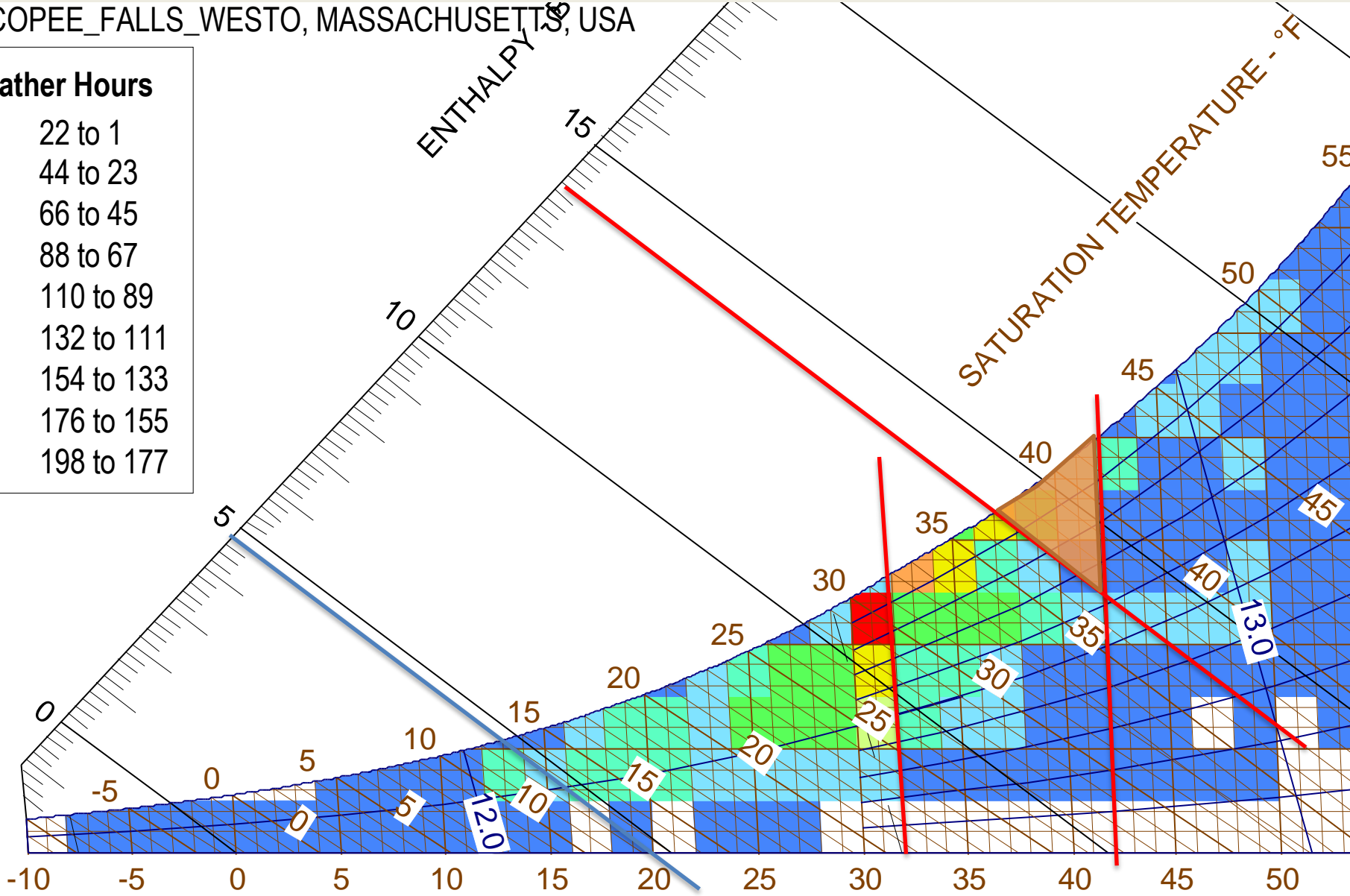
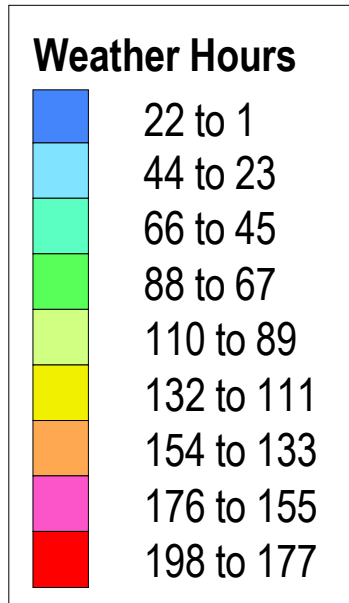
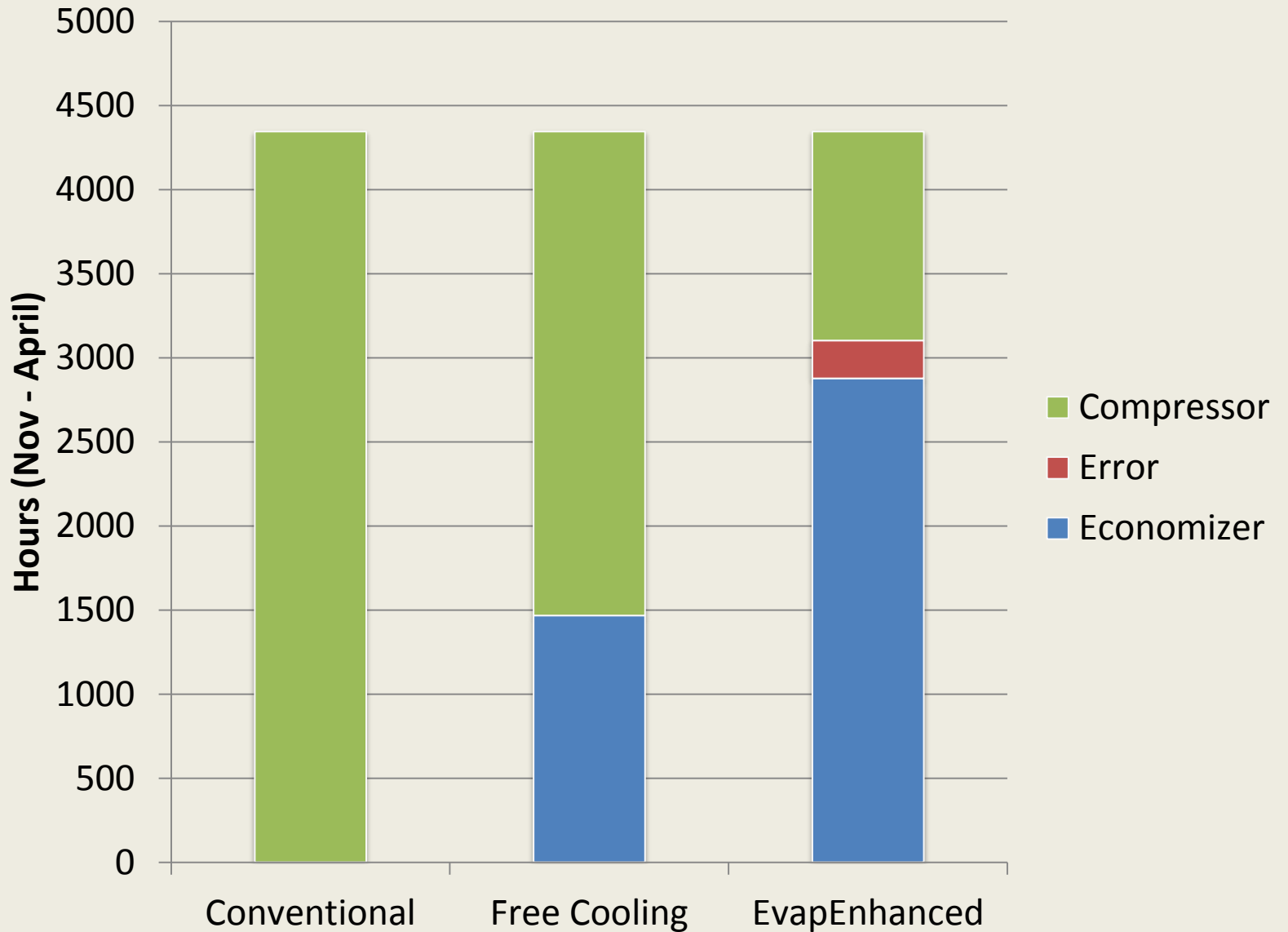


Chart by: **HANDS DOWN SOFTWARE**, www.handsdownsoftware.com

Weather-driven operating hours (for Chicopee, MA)



Energy usage and operating costs (based on Chicopee, MA weather)



First Cost and Simple Payback Period

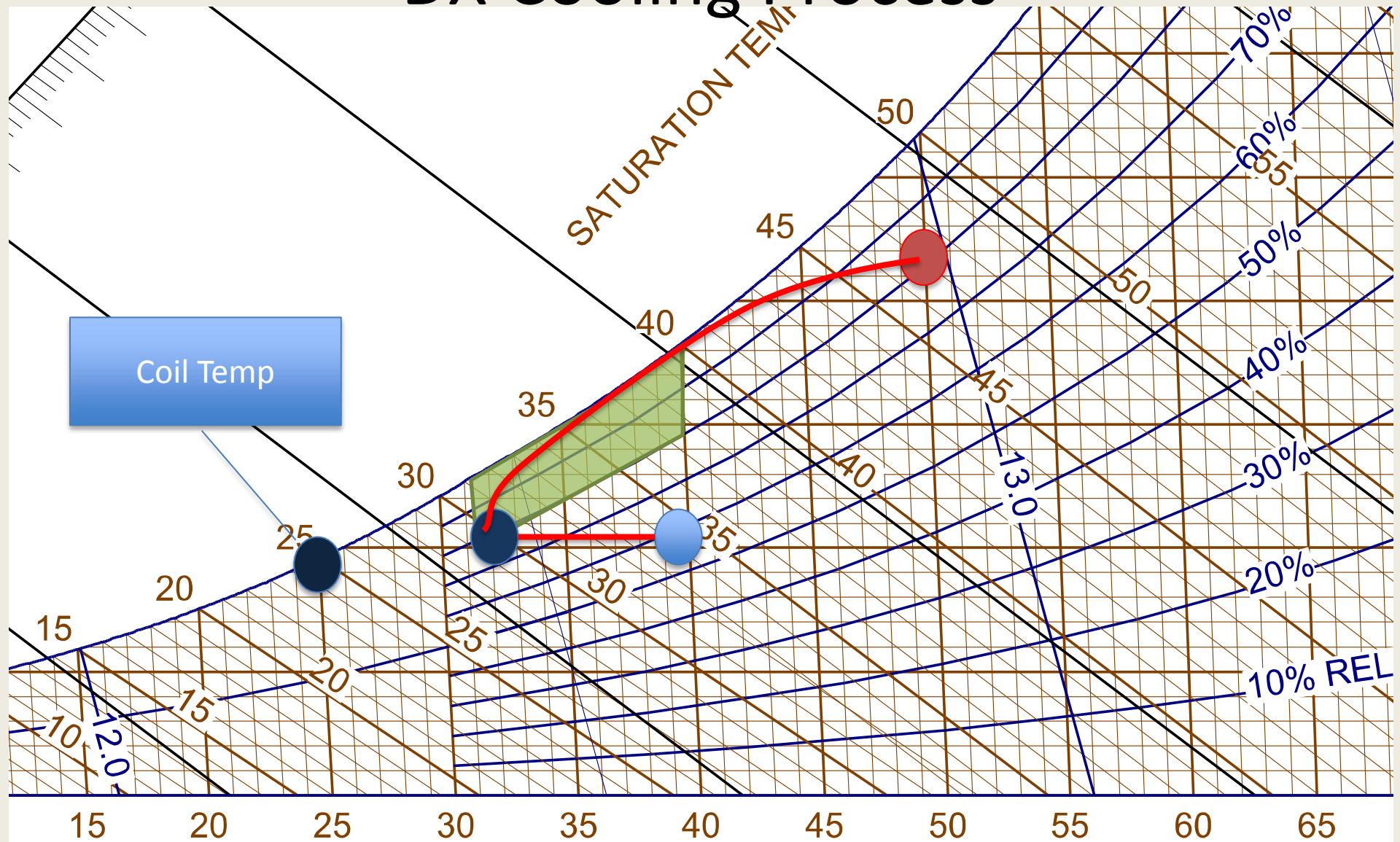
Item	Cost	Economizer only
Humidifier	\$900	N/A
Air intake fan	\$200	\$200
Circ. fan	\$40	\$40
Misc.	\$100	\$100
Total	\$1,240	\$340
<i>Savings</i>	<i>\$213</i>	<i>\$122</i>
Simple Payback	2.91 Years	2.78 Years

Humidifier savings probably bigger at larger scales



- Prototype is only 800 ft³
- Identical setup can work up to 12,000 ft³
- Humidisk10 can work up to 20,000 ft³ at 1 ACH.
- 70 CFM Circ fans will have to be multiplied (approx. 1 for every 1000 ft³.)

DX Cooling Process



Coil Temp

Vapor Profile of a Carrot in Storage

Vapor
Pressure:
0.689 kPa
35°F,
Saturated

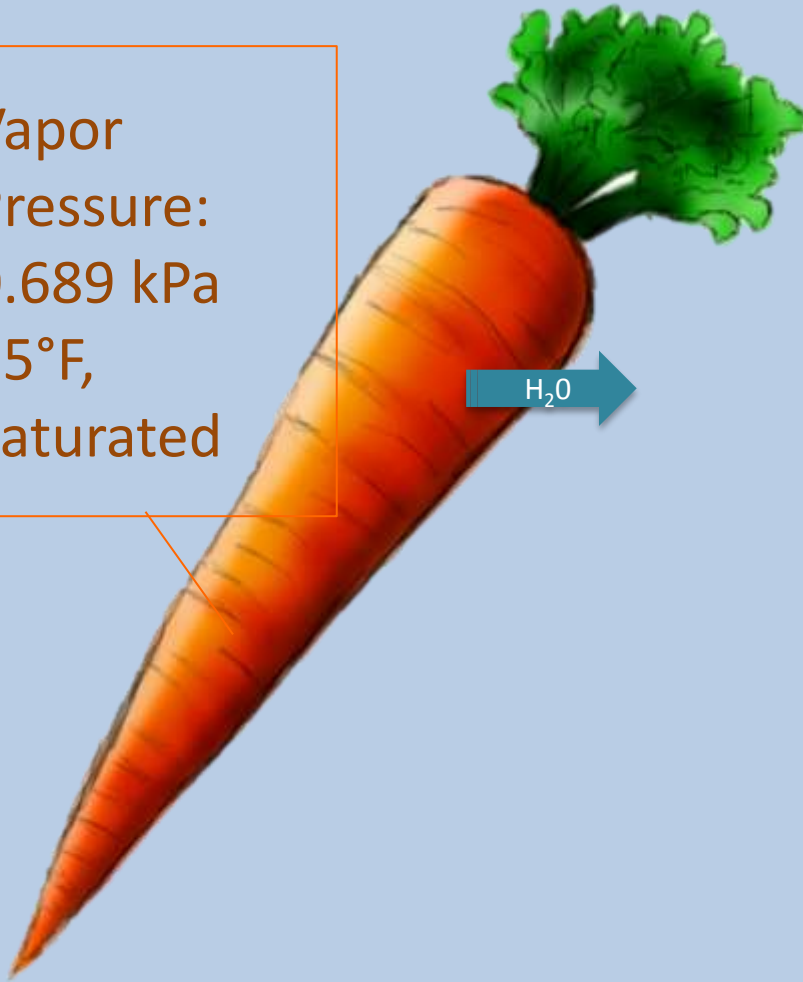
H₂O



Vapor Pressure:
0.414 kPa
35°F, 60% RH

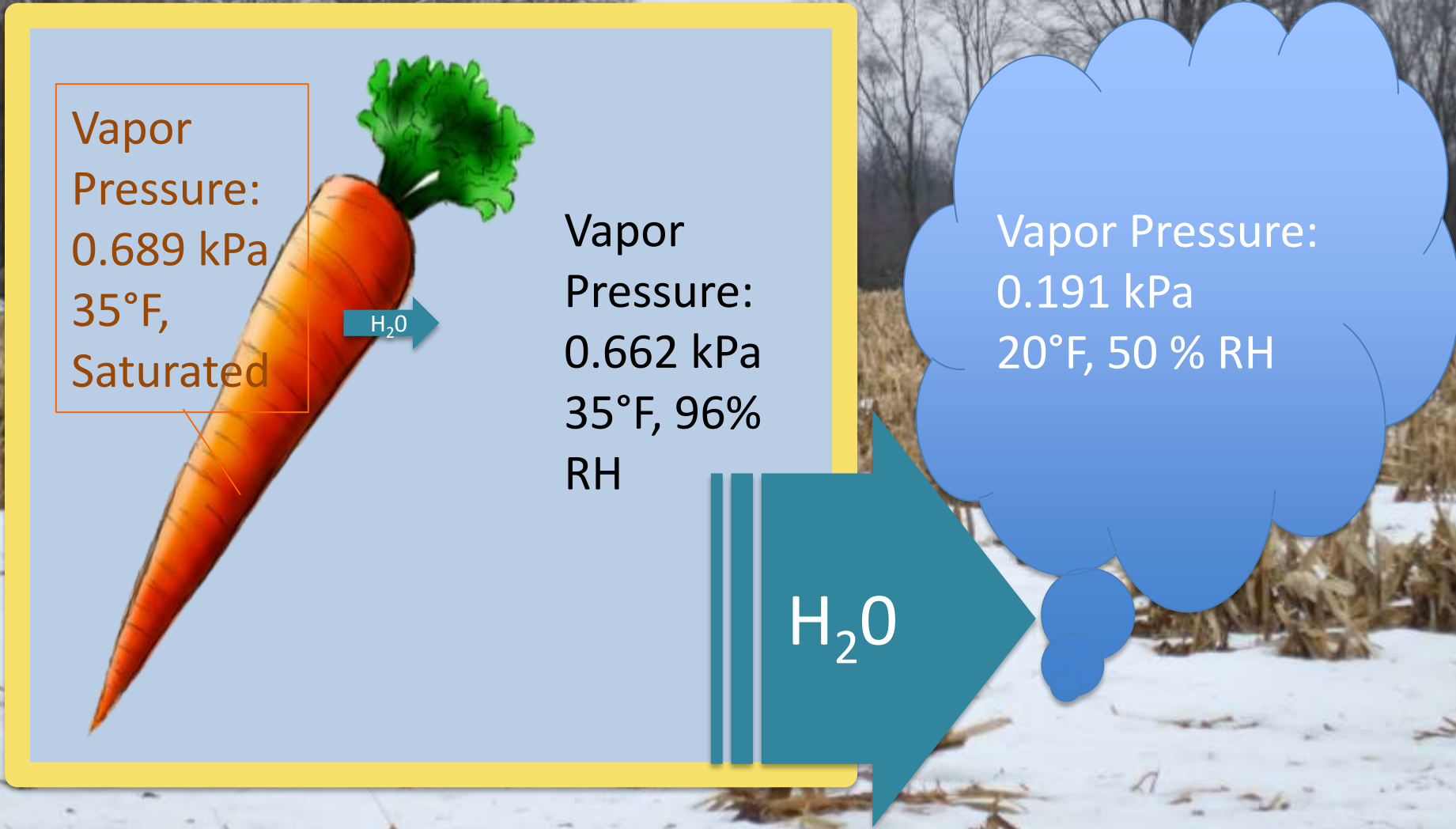
Vapor Profile of a Carrot in Storage

Vapor
Pressure:
0.689 kPa
35°F,
Saturated

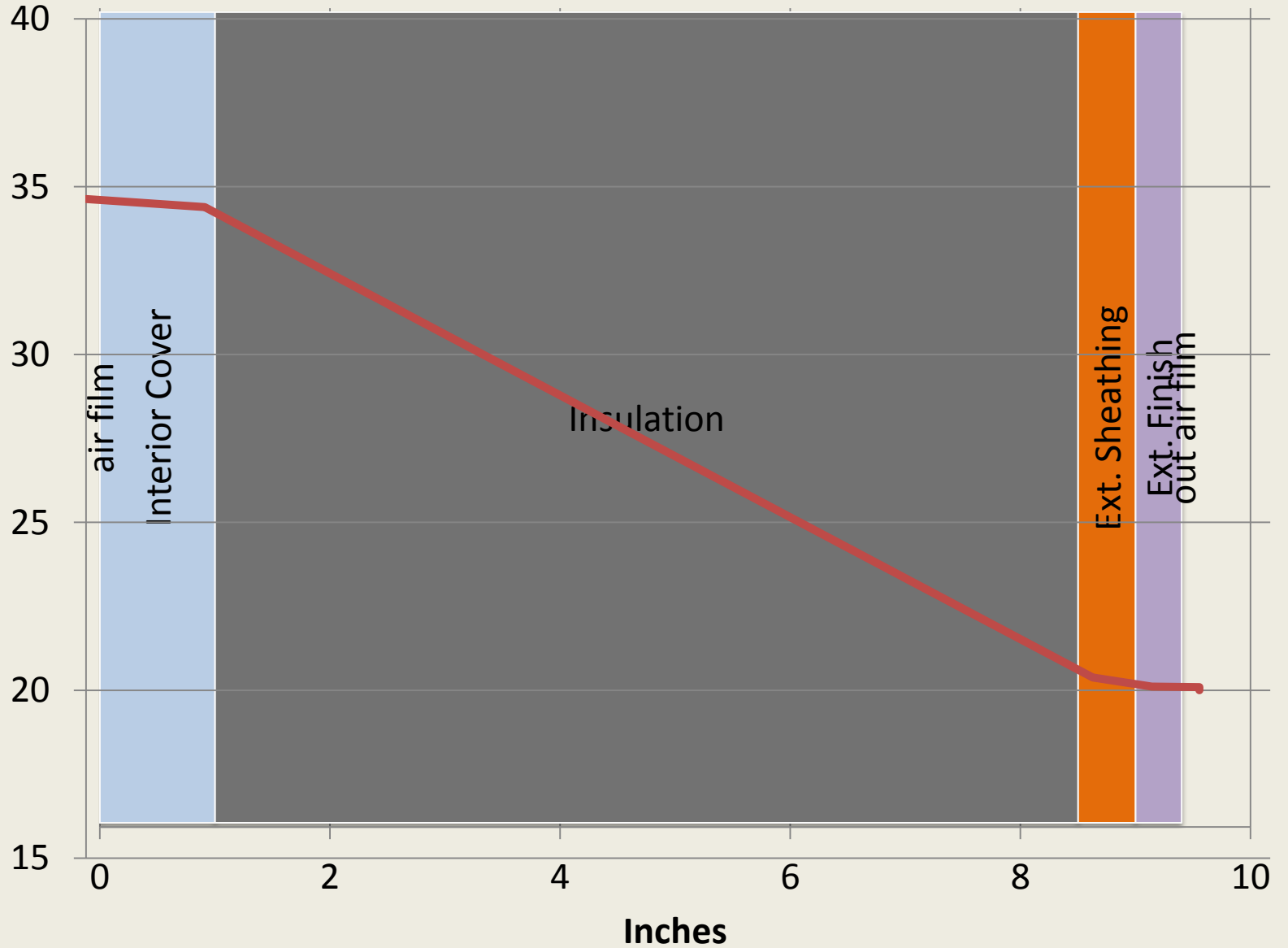


Vapor Pressure:
0.662 kPa
35°F, 96% RH

Vapor Profile of Carrot in Storage in Winter

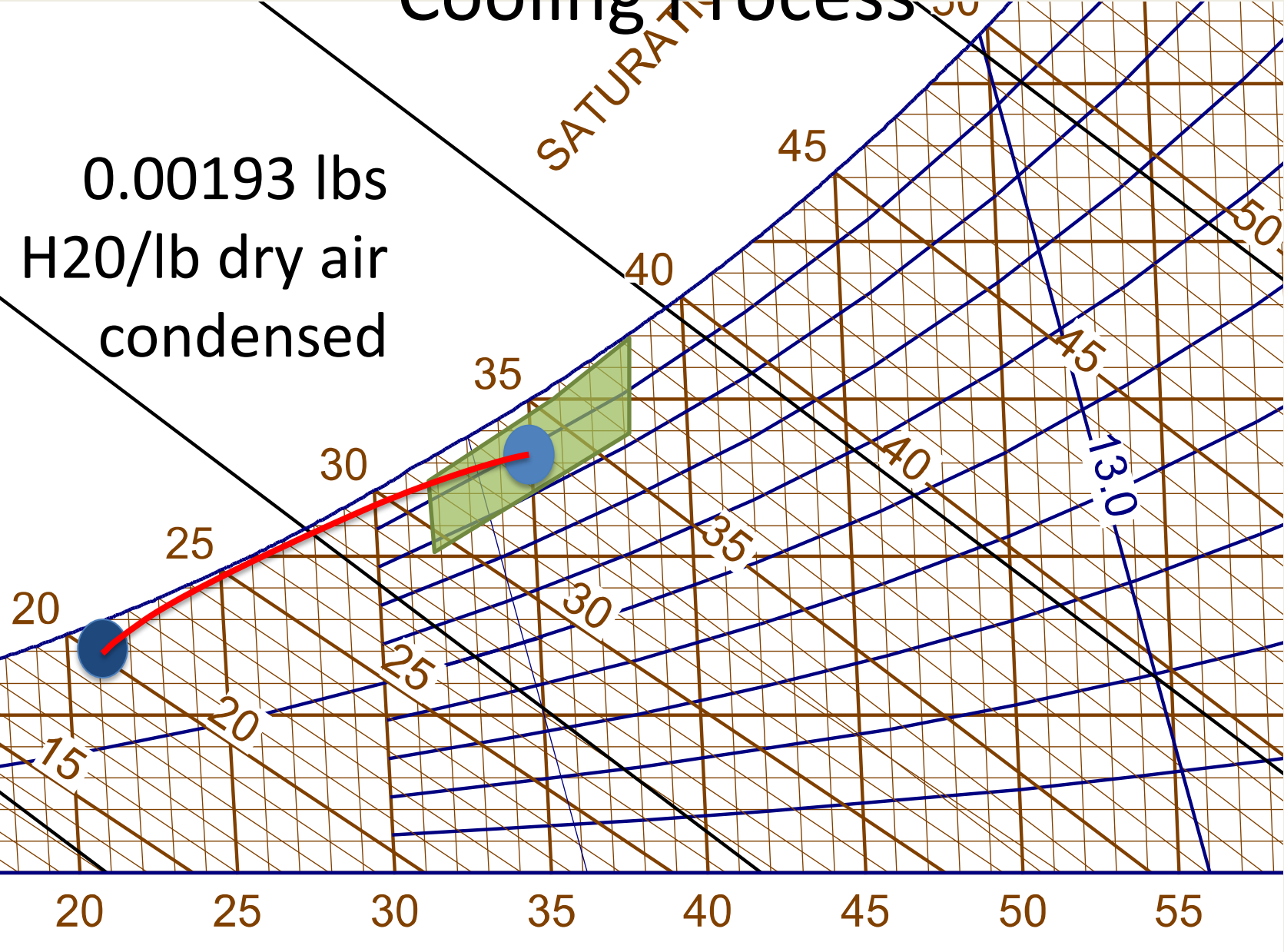


20°F Outside

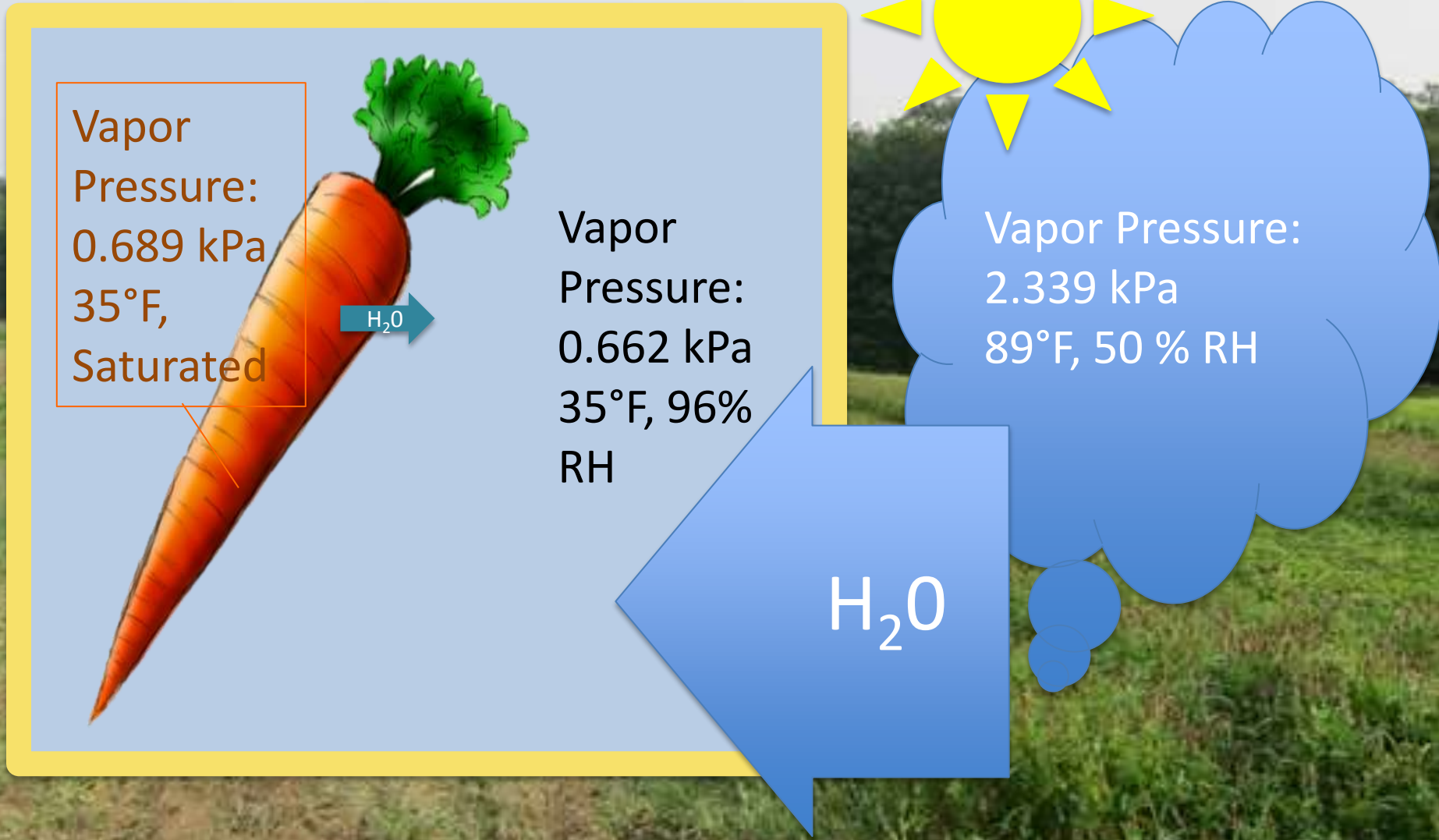


Cooling Process

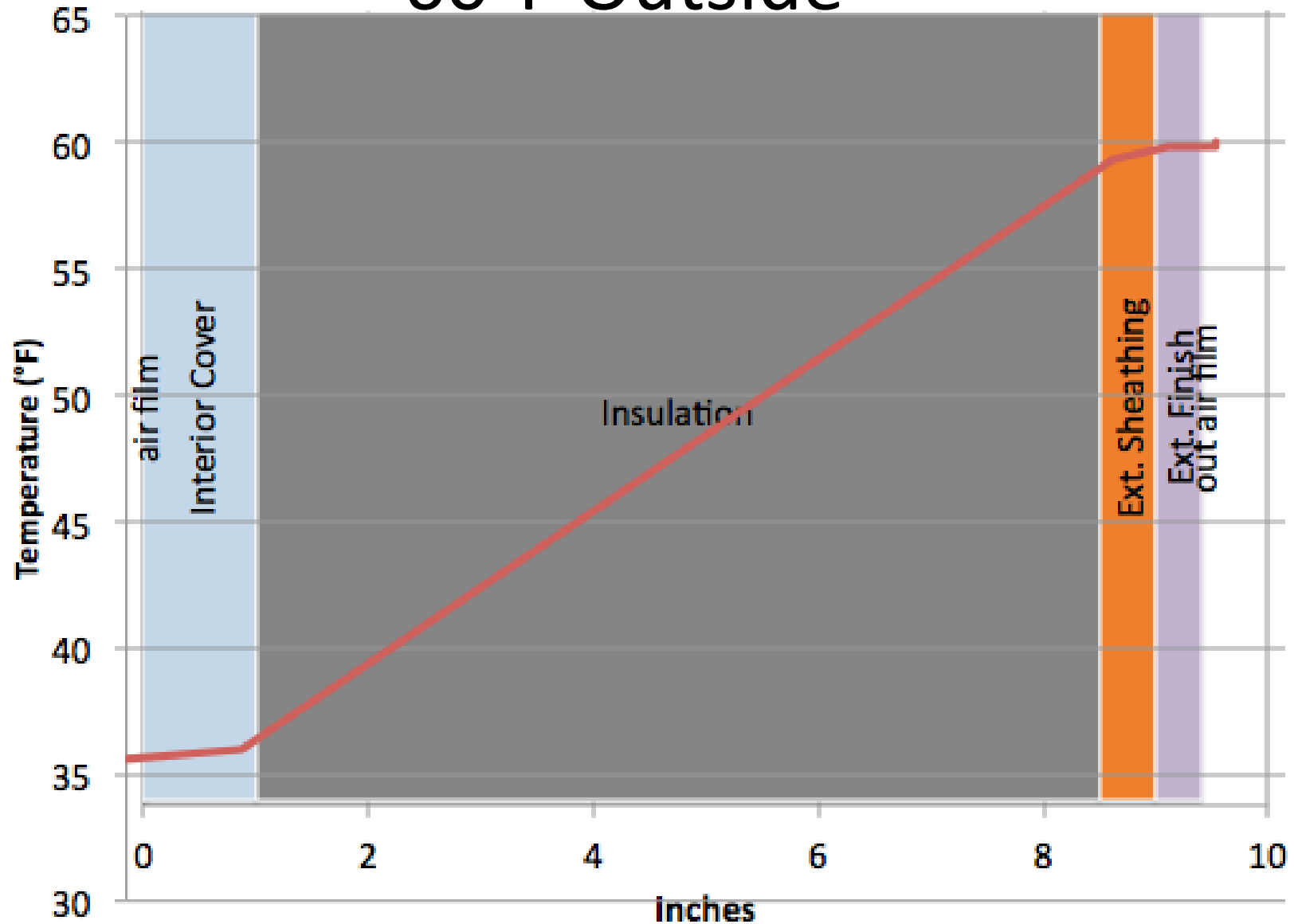
0.00193 lbs
H₂O/lb dry air
condensed



Vapor Profile of a Carrot in Storage in Summer

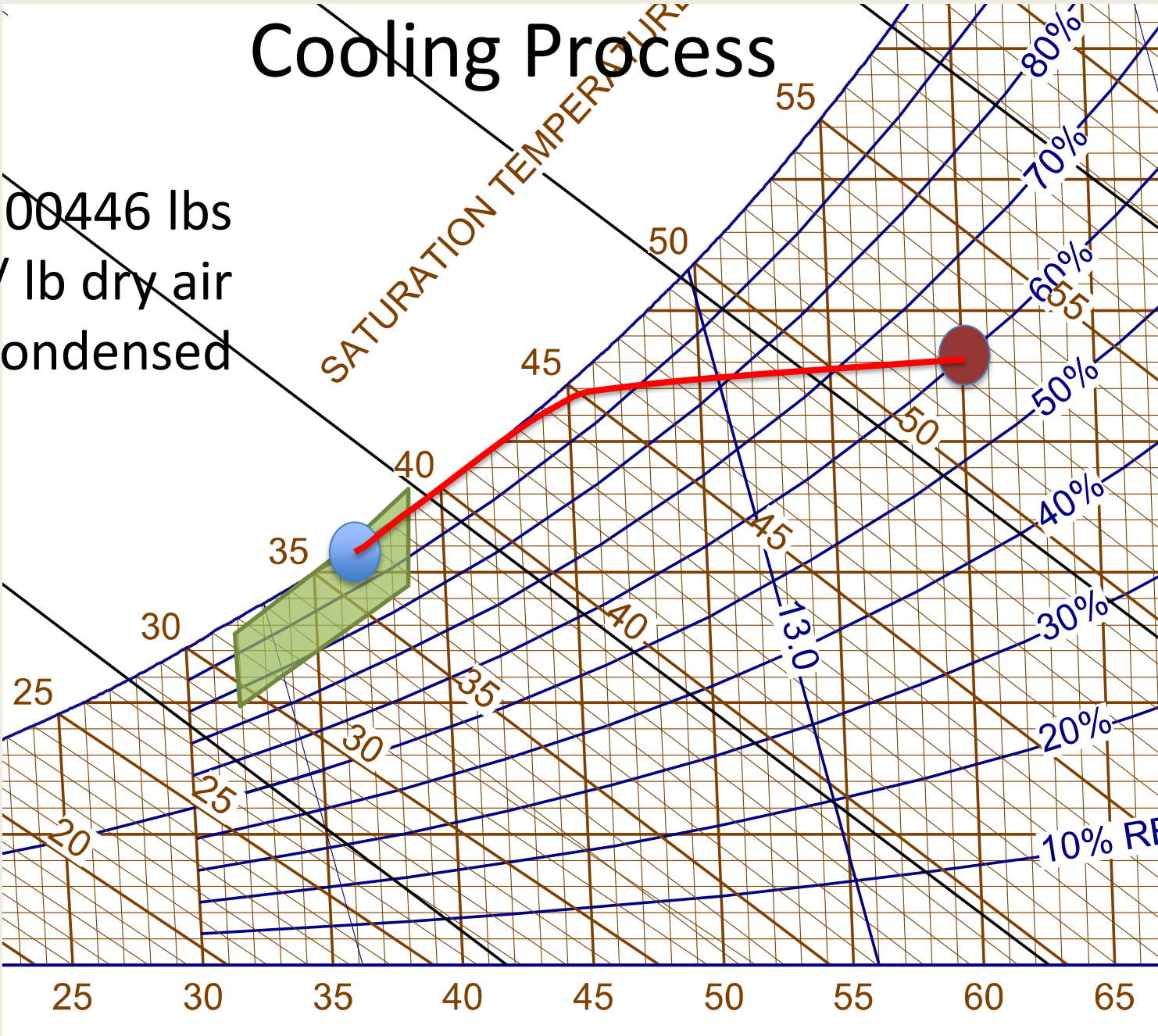


60°F Outside

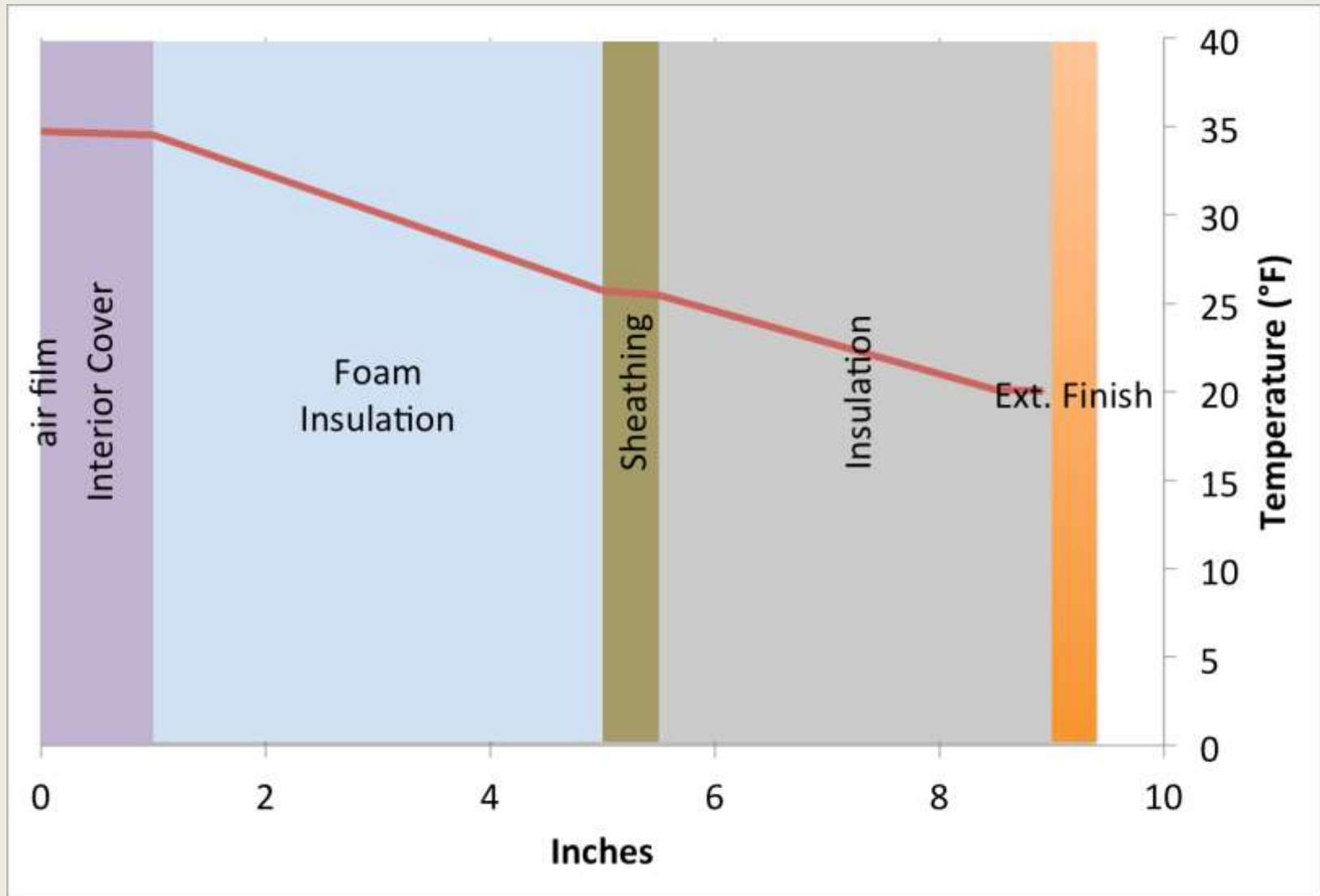


Cooling Process

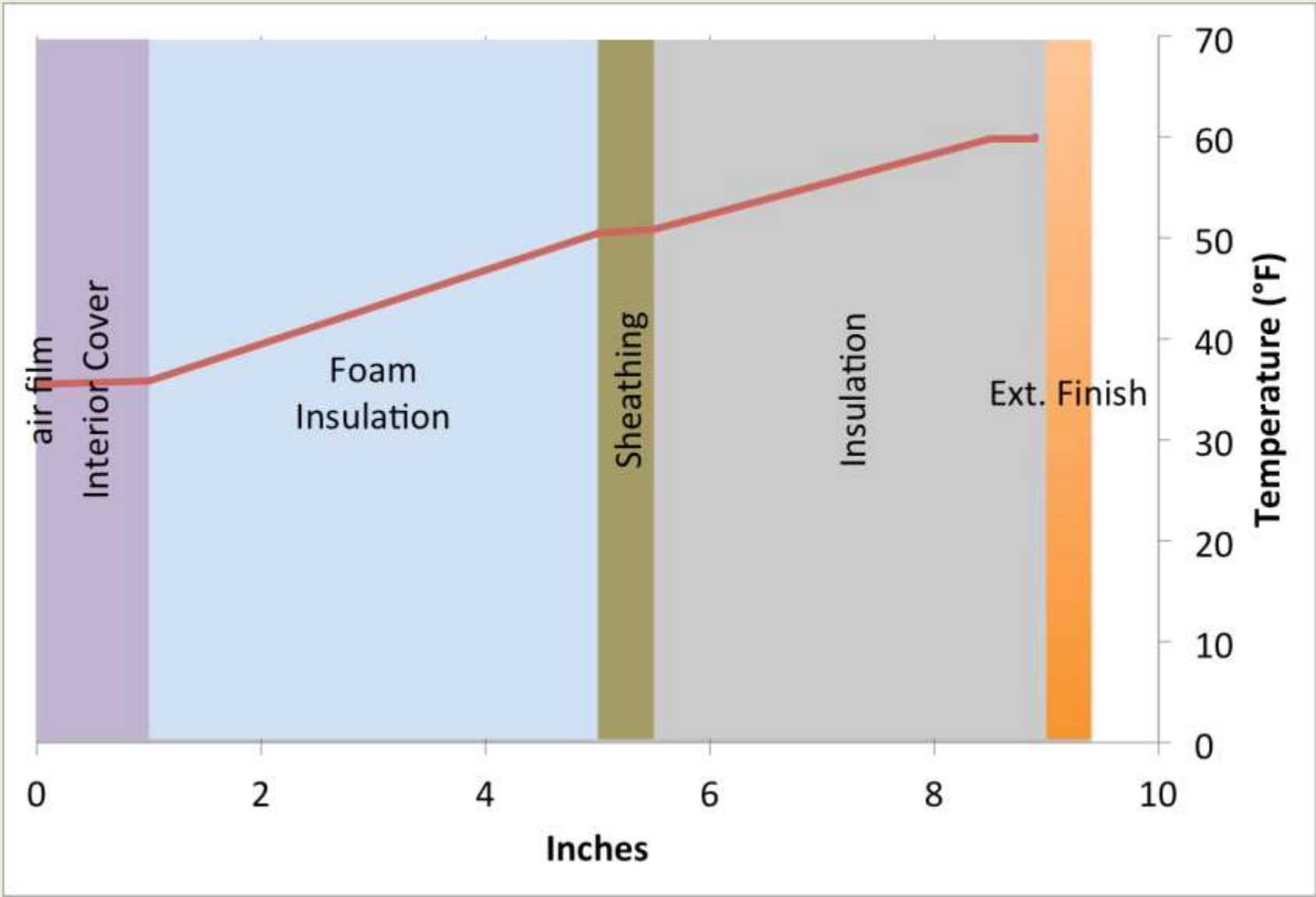
0.00446 lbs
H2O / lb dry air
Condensed

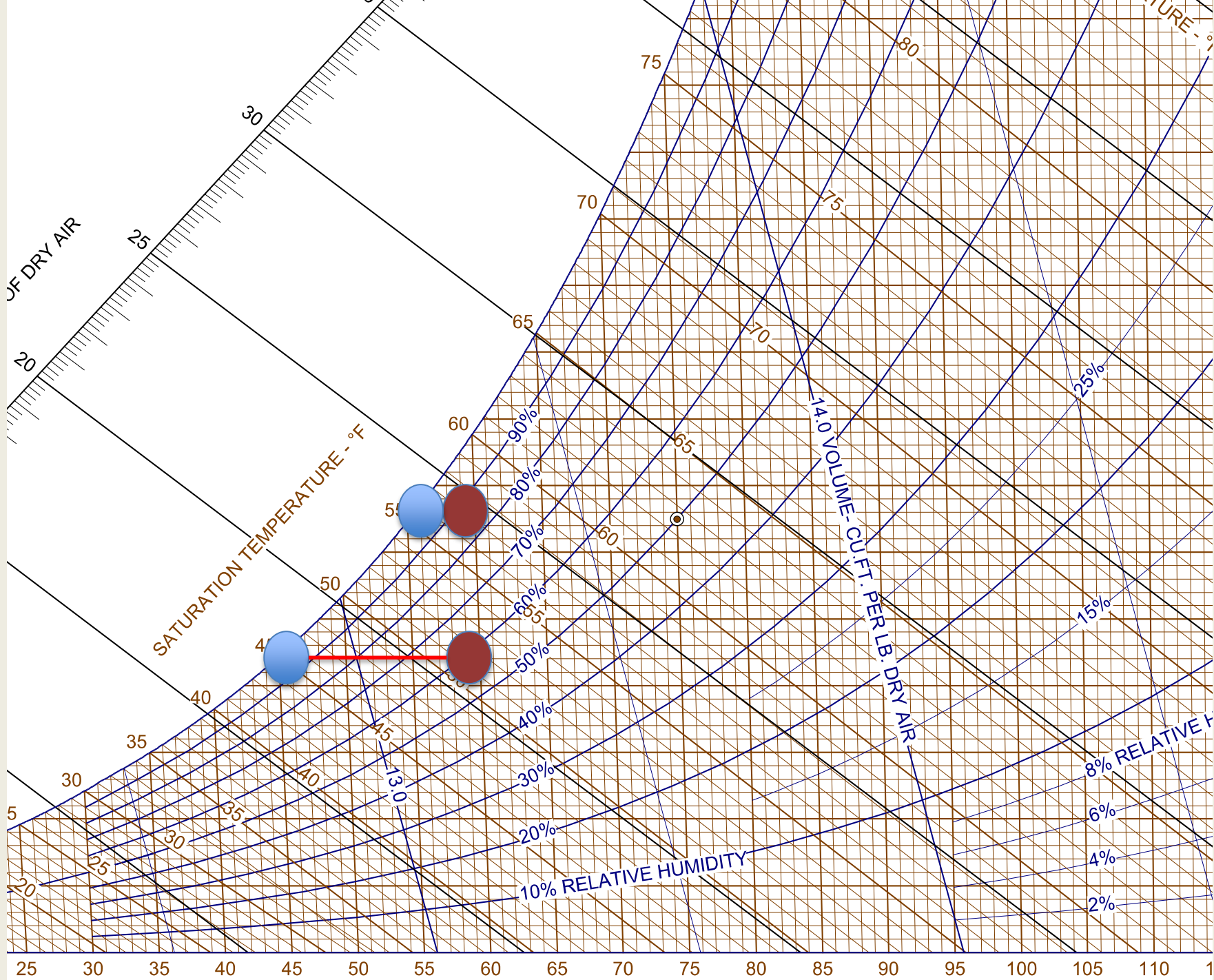


20°F outside

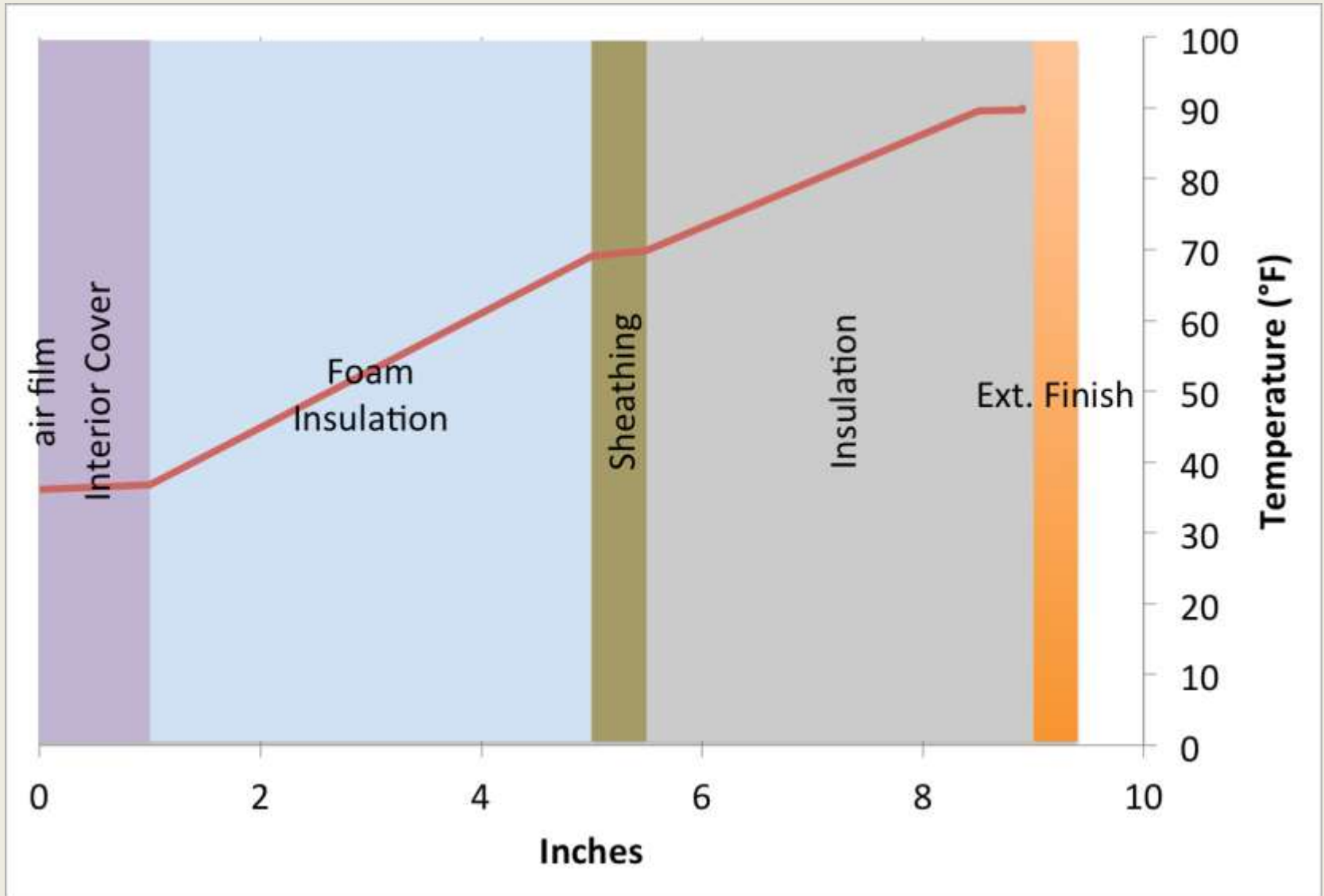


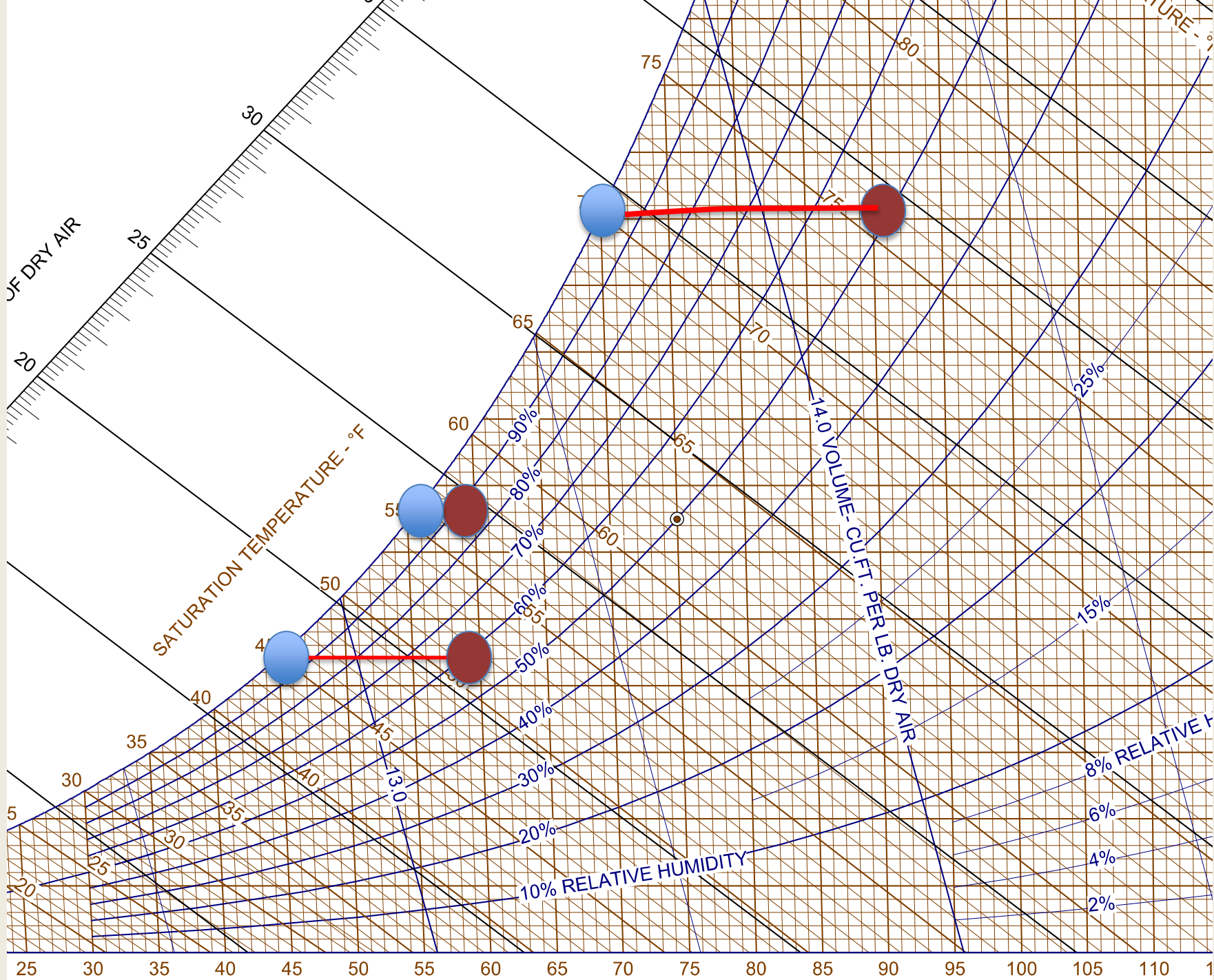
60°F outside





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



United States Department of Agriculture
National Institute of Food and Agriculture

Center
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Building and Construction Technology
University of Massachusetts, Amherst



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