Deep Winter Greenhouses: Passive solar production technology for Northern climates

A COMMUNITY-UNIVERSITY PARTNERSHIP
What is a Deep Winter Greenhouse?
How it all began

- Producer developed and led innovation
- Needed sturdy structures on MN prairie
- Refining designs from 1980’s gas price spikes
- Collaboration with now SWRSDP
Basic principles for passive solar greenhouse

- Minimizing costs with passive solar heat
- Uses readily available materials that are familiar to use
- DWG design is site-specific
- Used for cool, low light crops
Regional Sustainable Development Partnerships

Theory of change

– Solutions to today’s pressing issues need both community innovation and knowledge and university expertise
– Community is a source of innovations that can inform and support University research
– There is a need to connect community and University resources
– Community driven issues are inherently interdisciplinary
Clean energy and climate adaptation

U.S. Drought Monitor
California

Description: Mont Belvieu, TX Propane Spot Price FOB
Food deserts, Food Access, Farm Diversification
From the Ground Up

(Carl Ford, 2010)
Ready to Grow!

(Carol Ford, 2010)
Growing in the ground, and in the air
Ryan Pesch/ Lida Farm
AND MORE…
AND MORE…
AND MORE…

(Carl Ford, 2010)
RSDP DWG work

- Cold Climate Greenhouse Resource Manual (SE RSDP, College of Design CSBR, Eagle Bluff Env Learning Ctr)
- Extension block grant (College of Design CSBR)
- DWPA forming as a networking group with (SW RSDP, Bush Foundation, SFA)
- MN Drive Global Food Ventures (hort research, enterprise analysis, producer profiles, networking)
- DWG Campaign (IonE)
- Engaging with students (Design)
Deep Winter Producers Group

The Deep Winter Producers Group is a networking group of SFA.

Membership in this group is free. Contact Carol Fort at 320.226.5405 or deepwinter@sfa-mn.org

Deep Winter Producers Group Meeting
5 p.m. Sat., Nov. 7
St. Benedict's, Monastery, 104, Chapel Lane, Stillwater, MN (Refining) Building, Room A (just north of the College of St. Benedict Campus)

Are you interested in growing healthy, tasty produce in the depths of winter? Join us for a gathering of the newly formed Deep Winter Producers Group and find out what's going on in our state from winter greenhouse design to production and all points in between. We'll learn about the latest research in those innovative winter greenhouses, as well as exciting opportunities this winter to find out even more!

When the meeting concludes, you are welcome to join us for dinner at the nearby Connex Dining Center on campus. Great food; all you can eat for $12.

All experience levels welcome. Come join in the discussion with growers ranging from experienced greenhouse producers to beginners all pondering how to make it happen on their own farms.
Economic Performance

• Looked at 7 greenhouses
• Many end goals (education, research, production)
• Median construction cost $20,578
• Net earnings ranged from ($5/hr) to $20/hr (averaging 10 - 13 hours/week)
Future Needs and Research Opportunities

• Prototype DWGs for prospective technology adopters
• How to increase production in existing greenhouses
• DWG production curriculum
• Scaling up the model
• Different crops
• Soil mixes
• NRCS DWG in EQIP Program
Thank You
MNDRI VE: Reinventing Year-Round Food Production in Minnesota

Liz Perkus
M.S. Student - Applied Plant Sciences, UMN
John Erwin, Esther Gesick, Greg Schweser

Plant and soil health:
Carl Rosen, Julie Grossman, and Mary Rogers

Human Nutrition:
Justin Carlson and Joanne Slavin
Project objectives:

1. Quantify environmental differences between
   - Conventional greenhouses (C)
   - Deep Winter greenhouses (DW)

2. Determine how greenhouse environment affects crop growth and yield
   - Temperature
   - Light
   - CO₂
Greenhouse Sites

Conventional Greenhouses:
1. Bachmans
2. Bergens
3. Engwalls
4. Pork and Plants
5. Tangletown Gardens
6. UMN Twin Cities

Deep Winter Greenhouses:
A. Garden Goddess
B. Lida Farm
C. Paradox Farm
The Experiment:

- Selected existing greenhouses around the state (C–6, DW–3)
- Identified 5 crops to be grown at all sites

Mesclun Mix:

- Arugula
- Mizuna
- Red Giant Mustard
- Strawberry “Albion”
- Kale “Red Russian”

- Distributed seed, pots, and a scale
- Sites used own media and fertilizer
Data Collected:

- Production information
- Fresh weight at harvest
- Temp and light intensity every 15 min
- Photosynthetic response curves
Mesclun Mix Yield

- Arugula
- Mizuna
- Red Giant Mustard

Fresh weight (g)

Deep Winter
Conventional

1 pound
There is one resource that is **fundamental** to greenhouse plant production
Conventional Heated Greenhouse Daily Temperature
November – December 2014

Temperature

Time

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Deep Winter Greenhouse Daily Temperature
November – December 2014

Temperature

Time

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Average daily high

Average daily low

\[ p = 0.025 \]

\[ p < 0.001 \]

Days in Jan 2015

Average max \((^\circ C)\)

Average min \((^\circ C)\)
Photosynthesis

Sunlight → Sugar

Water → Oxygen

Carbon Dioxide
Measuring photosynthesis

<table>
<thead>
<tr>
<th>Light (μmol m⁻² s⁻¹)</th>
<th>CO₂ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 100, 200, 400, 600, 800, 1000, and 1200</td>
<td>300</td>
</tr>
<tr>
<td>400</td>
<td>50, 200, 400, 600, 800, 1000, and 1200</td>
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<tr>
<td>20</td>
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</tbody>
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Light Response Curve - Kale

Photosynthesis Rate vs. Light

DW and C represent different conditions or treatments in the experiment. The significance level, p = .293, indicates the statistical significance of the observed data.
CO₂ Response Curve - Kale

$p = .224$

Photosynthesis Rate

CO₂

DW

C

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Driven to Discover™
Conclusions:

• Deep winter greenhouses are productive!
• Very important to manage temperature on sunny days
• Production could increase with supplemental CO$_2$
Acknowledgements

- Undergraduate assistants: Julian Esparza, Victoria Hoeppner, Lindsey Miller, Sonora Nolan-Rapatz, Sam Voss
- Graduate students: Peyton Ginakes, Dan Raskin, Jared Rubenstein, Aimee Talbot
- Scientists: Esther Gesick and JiJY Sooksa-Nguyan
- Deep winter greenhouse sites: Garden Goddess, Lida Farm, Paradox Farm
- Conventional greenhouse sites: Bachman’s, Bergen’s, Engwall’s, Pork and Plants, Tangletown Gardens
- Minnesota Fruit and Vegetable Growers Association, Minnesota Nursery and Landscape Association
- Seward Cooperative, Lunds & Byerlys, Kim Barton
Questions?

Liz Perkus - eaperkus@umn.edu
DWG design development

2013:
Cold-Climate
Greenhouse Resource
Included winter greenhouses around MN
Surveyed various heating systems
Surveyed multiple scales
Surveyed multiple
2013:

DWG design for Eagle Bluff ELC

Designed to capture winter solar heat gain
Daytime heat stored in rock bed
Forced-air circulation
Teaching greenhouse
High-performance Greenhouse design
Net-Zero home $$$

Designed for human comfort and health
Designed for year-round use @ constant temp.
Uses passive and active solar systems
Some storage (DHW)
Insane amounts of insulation
Designed to generate as much power as it uses
Net-Zero home $$$

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Hoop house $

- Designed for plant comfort
- Designed for season extension (spring and fall)
- Uses passive solar gain
- No heat storage
- No insulation
Net-Zero home $$$
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Hoop house $
Designed for plant comfort
Designed for season extension (spring and fall)
Uses passive solar gain
No heat storage
No insulation

DWG $
Designed for plant comfort and human health
Designed for winter use
Uses passive and active solar systems
Some storage (thermal mass)
Sensible amounts of insulation
Designed to minimize supplemental heating fuel usage.
Initial research questions

• How to optimize solar *heat gain* in deep winter?
• How to *retain* heat?
• How to *improve construction details*?
Heat capture
or
Heat gain
Optimizing

Solar heat gain is best when rays come in *perpendicular* to the glazing.

Nov. & Jan.
Dec.

Section through main growing space
Optimizing heat gain: Glazing angle

Solar heat gain is best when rays come in \textit{perpendicular} to the glazing.

Glazing wall should be sloped at 60º to optimize deep winter heat gain.

Nov. & Jan.
Dec.

Section through main growing space
Optimizing heat gain: Glazing angle

Steep angle dumps snow, so less framing materials are needed, meaning less light is blocked.

30° angle with 2x8 24” o.c.  
Elk’s Bluff

60° angle with 2x4 48” o.c. + purlins  
Paradox Farm
Optimizing heat gain: Glazing angle

Steep glazing wall can also help reflect heat during the summer months.

Heat gain drops significantly when incident angle is >65°
Conventional Heated Greenhouse Daily Temperature
November – December 2014

Temperature

Time

75°F

50°F

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Deep Winter Greenhouse Daily Temperature
November – December 2014

Temperature

- 114°F
- 95°F
- 75°F
- 50°F

Time

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How to *retain* heat?

- Thermal mass
  - Heat transfer to and from thermal mass
- Insulation
- Airsealing (construction detailing)
Heat storage
Optimizing heat storage: Thermal mass

Thermal mass *absorbs and releases heat* to stabilize the temperature.

Subterranean Heating and Cooling System

Underground Heat Exchange System

Geothermal

Thermal banking

Earth Charger

Ground-to-air Heat Transfer

Climate Battery

Geo-Air Greenhouse
Optimizing heat storage: Thermal mass

• Rock vs. Water
  – Rocks are cheap
  – Air is cheap and simple to move

• Basic design is air pushed through a bed of rocks.
Heat transfer: Airflow through rock bed

Seeking to *maximize contact* of air with rock surface, how do you encourage air to move through *entire* thermal mass?

“Finger-jointed” duct layout maximizes pathways for air to travel through rock bed.
Heat transfer: Airflow through rock bed

Seeking to maximize contact of air with rock surface, how do you encourage air to move through entire thermal mass?

“Finger-jointed” duct layout maximizes pathways for air to travel through rock bed.
Heat transfer: Airflow through rock bed

Resistance to airflow = $$ for electricity for fans

Typical duct layout to reduce friction: Trunk and branch
Optimizing heat storage: Heat transfer

- Duct fan placement
  - More efficient to move cool dense air vs. hot air at peak.

![](image)
Optimizing heat storage: Heat transfer

- **Humidity**
  - Latent heat is released to rocks upon condensation.
  - **BUT** possible danger of mold/microbial growth.
    - No record of indoor air quality problems with *greenhouse* underground heat storage.
    - Very problematic in residential use for IAQ.
    - Good design can mitigate problems, but is an area where more study is needed.
Heat retention
Insulation *around thermal mass*

- Insulation is most useful when there is a large difference in temperature.
- In MN, frost depth is ~40in. (below that, temp is relatively stable 50ºF)
- Thus, insulation investment is best at perimeter of thermal mass, NOT underneath.
Optimizing heat storage: Insulation
Insulation *above grade*

- North wall and roof are most crucial.
  - North wall because 0 thermal gain occurs.
  - Roof because thermal pressure is greatest.
Energy Audits performed on 3 DWG’s

- Blower door test (measures draftiness)
- IR camera readings (show where drafts are)
- Recommendations
Energy Audits performed on 3 DWG’s

• Elk’s Bluff, Montevideo
• Lida Farm, Pelican Rapids
• Paradox Farm, Ashby
Good news from Energy audits!
IR camera shows that thermal mass is working.

Floor temperature of 79°F

Outside air temperature 62°F

Inside air temperature of 71°F
Other news from Energy audit: Blower door shows two of three greenhouses are drafty.

<table>
<thead>
<tr>
<th>Site</th>
<th>Volume</th>
<th>ACH@50</th>
<th>ACHnat</th>
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<tbody>
<tr>
<td>Elk’s Bluff</td>
<td>4488</td>
<td>4.34</td>
<td>0.31</td>
</tr>
<tr>
<td>Lida Farm</td>
<td>6912</td>
<td>14.37</td>
<td>0.84</td>
</tr>
<tr>
<td>Paradox Farm</td>
<td>4450</td>
<td>20.65</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Higher numbers indicate more drafts.
IR camera shows where leaks are.

Darker spots show cold air infiltration
Keeping the heat in: Airsealing

Only a few sealants are compatible with polycarbonate!

- Henkel  
  PL Ultimate Hybrid Sealant
- Franklin Int’l.  
  Titebond 100% Silicone Sealant
- Franklin Int’l.  
  Titebond Metal Roof Sealant
- BASF  
  Degabond 54 Structural Adhesive
- Tremco  
  Dymonic Polyurethane Sealant
- DAP, Inc.  
  100% Silicone Rubber Sealant (50yr.)

Improving construction details

• Minimize dangers of condensation
• Durable, healthy materials
  – Low-impact materials
Minimize condensation dangers

- Humidity is expected and necessary
- Condensation can rot structure
- Can cause mold / microbe growth
Follow-up research

- More energy audits to increase data pool.
- What presence, if any, of airborne microbes/mold that could affect human health?
- How to effectively integrate nighttime insulation into structure?
RSDP Prototype document format

• Narrative on system selection.
• Reasoning for design aspects.
• Construction document set for modest 450-500ft² standalone greenhouse.
• Material cost estimates. (~$15,000)
• Expected completion Dec. 2015.