A TRULY GREEN GREENHOUSE

A PRESENTATION BY

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A TRULY GREEN GREENHOUSE

- BACKGROUND
- HOW IT WORKS
- MODELING / DESIGN SPECS
- TECH TRANSFER

BACKGROUND

Larry Kinney of Synergistic Building Technologies, a long-time colleague of the presenter, developed the green greenhouse design. His concerns arose from the following realities:

- Most of the food Americans eat, particularly in winter, endures trips of up to thousands of miles from the field to the table.

- Food destined for such journeys must be harvested well before it is eaten, packed for shipment, and jostled around in trucks (or even airplanes) on its way to distribution centers, grocery stores, and pantry shelves.

- The result is less-than-tasty-or-fresh food whose embodied energy for transportation alone can be substantial.

This presentation is part of a continuing series of collaborations that seek solutions to these dilemmas.

BACKGROUND

Greenhouses have long been used to extend the growing season, enabling later harvests in the fall and earlier starts in the spring. However, conventional greenhouses like this hoop house require lots of auxiliary heat to keep crops from freezing on cold nights ($100s to $10,000s/year). Further, growth rates in mid winter are low. This is because they are poorly insulated and have very little thermal mass.

BACKGROUND

In 2010, Synergistic Building Technologies (SBT) initiated a demonstration project for a greenhouse that combined the best practices of building energy design and organic farming; ~ 1,000 square feet

The project was sponsored by the Colorado Department of Agriculture's Advancing Colorado's Renewable Energy Program

Motivated by the high energy costs of traditional greenhouses, SBT's design takes the next step in "greening" greenhouses

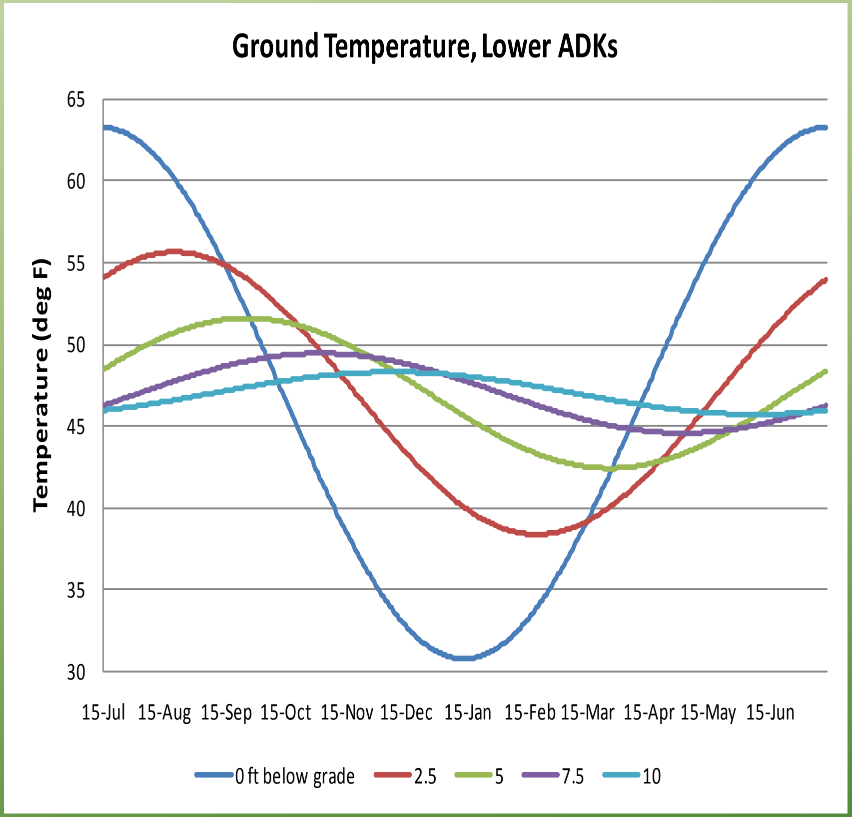
This presentation overviews the Green Greenhouse and outlines an initiative to transfer the greenhouse technology to New York State and the Northeast

HOW IT WORKS:
Design Features

Design features that <u>won't</u> be detailed in this presentation:

- Insulation (R-20 min; demo's average of ceiling and walls is R-35)
- Air sealing (710 CFM50 blower door test)
- Ventilation (existing systems OK)
- Moisture regulation (depends on location, crops, etc)

Design Feature: Deep Earth Temperature Coupling



Most Greenhouses Don't Take Advantage of What the Earth Has to Offer

- Surface temperatures follow air temperatures
- The deeper you go, temperature fluctuations are dampened and delayed
- The goal is to couple to deep-earth temperatures while decoupling from the surface temperature

Perimeter Foundation Insulation
for Deep Earth Temperature Coupling

- Originally engineered for residential structures

- Most heat loss occurs horizontally through the edge of the foundation slab or walls

- Photo on right shows lower plate bolted in place; note R-20 perimeter insulation

Perimeter Foundation Insulation
for Deep Earth Temperature Coupling

Greenhouse Innovations

- Prevents heat loss through the lateral margin of the enclosed soil volume

- Enclosed volume is thermal mass, storing about 25 Btu per ^{o}F above interior air temperature per cubic foot of soil

- A "thermal bubble" develops within a year that brings the temperature of the enclosed soil volume to at least 60^{o} F – ideal for roots year-round

- This combination of form and function has never before been used in a greenhouse design

Design Feature: Light Shelves and Glass Selection

- Roof surfaces and light shelves in front of windows, metal painted with high-gloss white paint, enhances net gain, partially diffuses light.
- The combination of high Solar Heat Gain of inexpensive glass and reflectivity from white surfaces raises the light-and-heat-gathering per unit of fenestration area by almost a factor of 2X
- This allows for less fenestration (and more wall insulation), so lowers overall energy losses while ensuring adequate light for plants.

Design Feature: Insulating Shutters

- Insulating shutters of several varieties, R value 12+, close tightly over each glazing surface on winter nights.

- In winter, shutters are automated to open when solar gains exceed thermal losses, to close when thermal losses exceed solar gains.

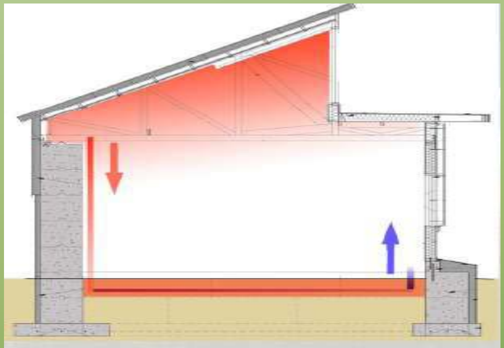
- May be partially closed in the summer to control for overheating in coordination with venting. Shutter surfaces are highly reflective, as are other surfaces in greenhouse except for earth and plants.

Pocket shutter on roller ready for install

- Net effect is to ensure that most solar light entering the greenhouse falls on plants and earth but is both diffuse and controllable.

Design Feature: Greenhouse Earth Thermal Storage (GETS) System

- When the greenhouse is closed and the sun is not shining, there is little temperature difference between the ground and top of the greenhouse.



- When sun is shining, the top goes to 100F + and is humid.

- GETS fan pulls air from top and distributes it in network pipes in the soil. Air dumps moisture and heat in earth, cool dry air emerges at ground level.
- Stores heat in earth mass, modulates temperatures in all seasons, waters plants from underneath.

Summary of Design Features

Heavy Wall and Roof Insulation:
Minimizes winter-time heat losses; allows for year-round ***harvests***

High Solar Heat Gain Glazing and Light Shelves:

Minimizes the area of windows needed for vigorous plant growth

Automated Insulating Shutters:
Reduces heat loss at night and heat gain in the summer

Thermal Mass: Holds heat and prevents drastic temperature swings

Controls, Controls, Controls:
For all sub-system operations (ventilation, shutters, CO2 levels, etc)

Perimeter Foundation Insulation:
Creates a 65° F+ “thermal bubble” for soil temperature year-round;
GETS system

Comparison of Greenhouse Designs

and sources of info presented on the next slide

-- Present State of the Art --

Hoop House

"Shed" Style

- National Sustainable Agriculture Information Service (NSAIS)
http://attra.ncat.org/attra-pub/solar-gh.html#heat

- Alward, Ron, and Andy Shapiro. 1981. Low-Cost Passive Solar Greenhouses, National Center for Appropriate Technology, Butte, MT.

- NRAES-33_Ithaca Greenhouse Guide.pdf
http://host31.spidergraphics.com/nra/doc/Fair%20Use%20Web%20PDFs/NRAES-33_Web.pdf

-- The Green Greenhouse --

- CO Department of Agriculture Reports
http://www.colorado.gov/cs/Satellite/Agriculture-Main/CDAG/1184661927876

- Ongoing performance monitoring at multiple sites

- Design simulations

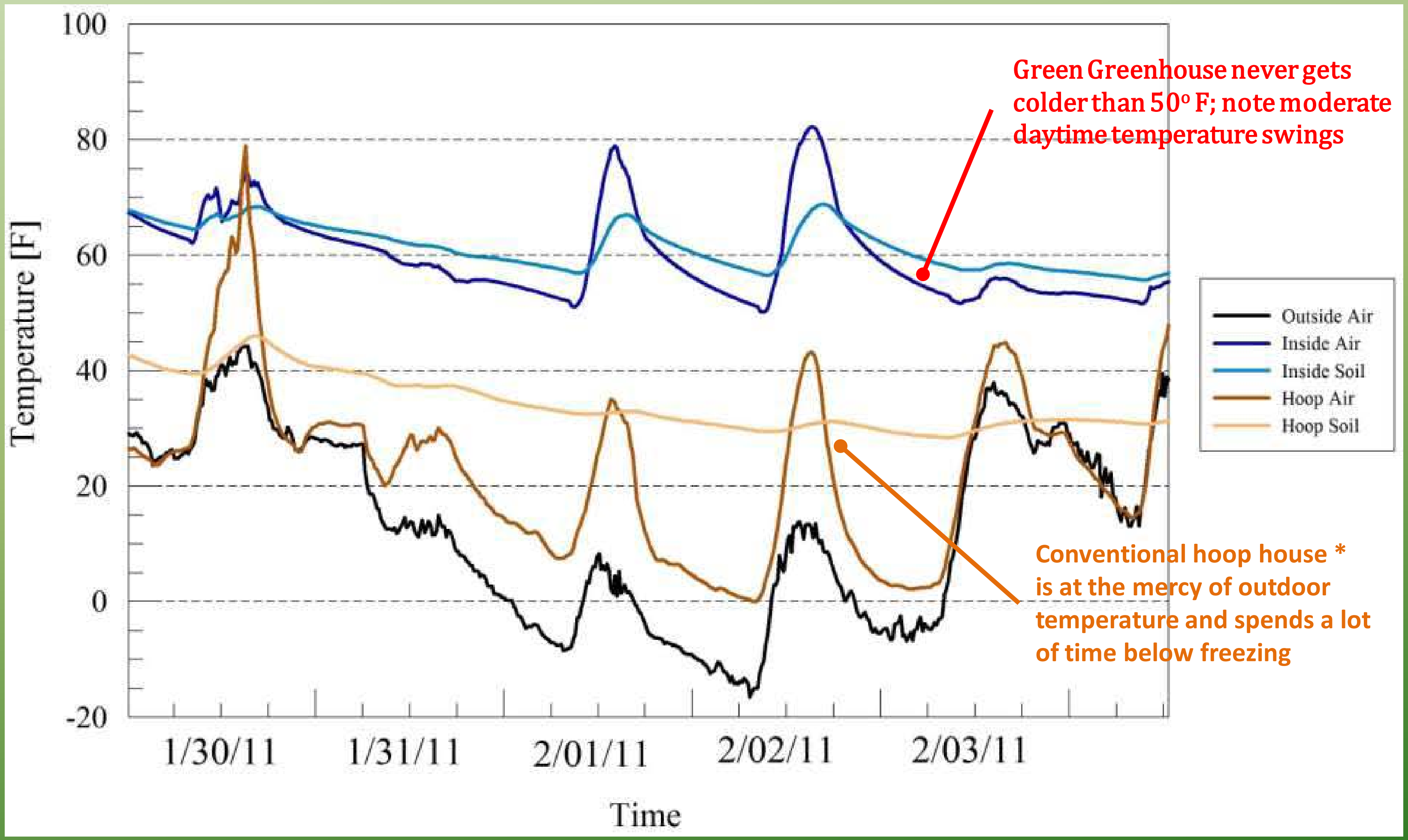
- Publications and tech transfer in progress

Design Feature	Hoop	Shed	Green Greenhouse
Perimeter Foundation Insulation	None	None	Standardized
Thermal Mass: Soil Capacity	Difficult to protect from exterior conditions	Variable depending on builder	"Thermal bubble" maintains 60-65 degrees year round
Thermal Mass: Wall	Very low	Variable depending on builder	Generally minimized due to soil capacity; add as needed
Window Area	N/A	0.7 to 1.5 sq ft per sq ft floor area	~ 0.5 sq ft per sq ft floor area
Insulating Shutters	None	Variable depending on builder	Standardized, US Patent 8,165,719
Light Shelves	None	None	Optimized for crops and location
Wall Insulation	Very low	Extremely variable; best case ~ R20	R35 or better
Centralized Monitoring & Control System	Minimal	Variable depending on builder	Standardized
Subterranean Moisture Circulation	None	Variable depending on builder	Standardized & integrated with central controls

Temperature Performance (Colorado)

Cold Snap Down to -18º F

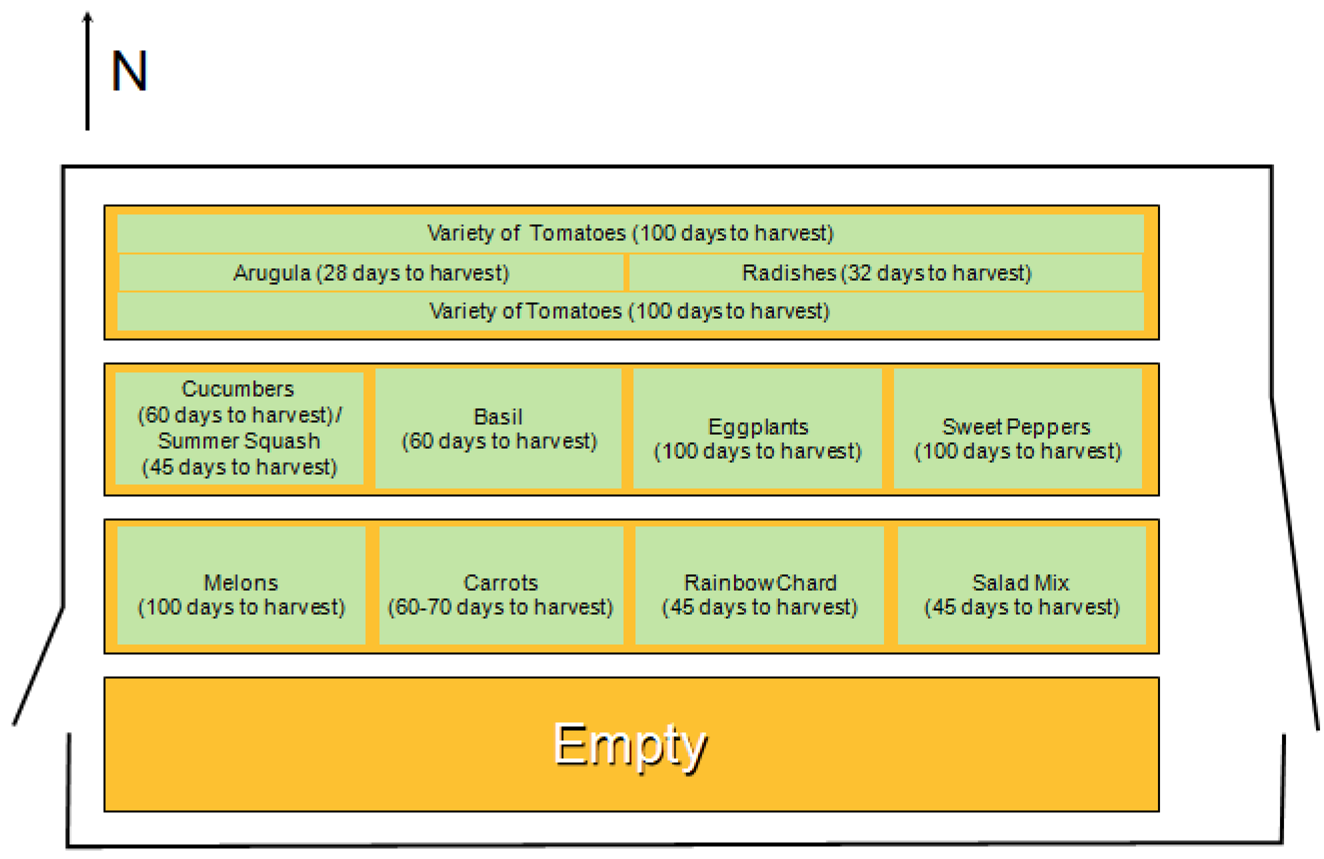
Sole Heating Source: Sunlight



* The hoop house is a plastic-covered frame adjacent to SBT's demo greenhouse

Crop Performance

Planting Plan
(planted on Thanksgiving Day 2010)



Crop Performance

16 Days after Seeding

Crop Performance

Outside: Snowy January Day
Inside: Summer-Like Conditions

The only source of heat needed in Colorado is sunlight

Crop Performance

The tomato vines four months after seeding

Perennials capable of bearing fruit continuously

HOW IT WORKS: Economics

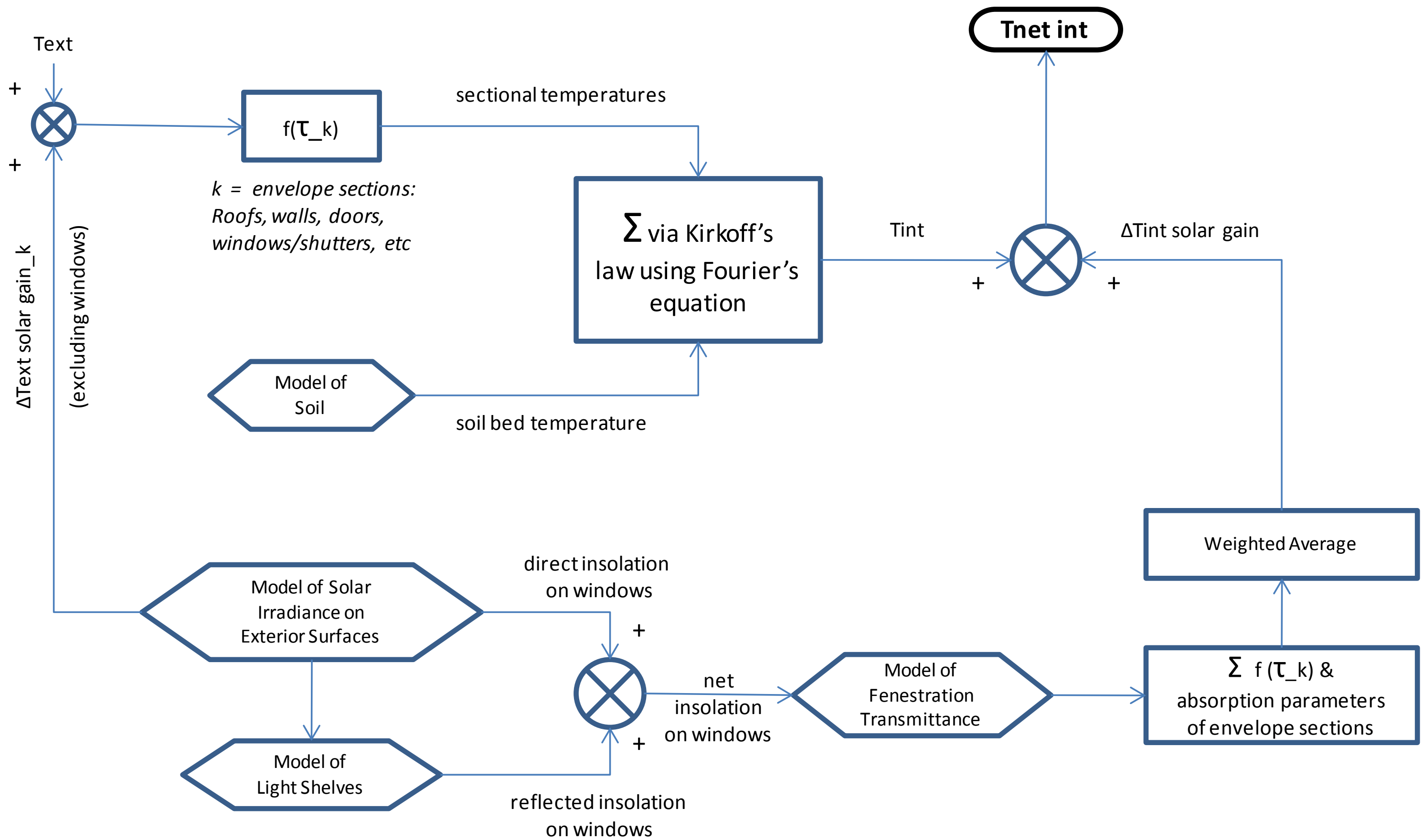
Example annual cash flow from 3,000 ft2 Green Greenhouse costing $80/ft2 with 50 yr life versus conventional greenhouse (BAU) costing $30/ft2 with 12 yr life

	Years 1-12		Years 13-50	
	Green	**BAU**	**Green**	**BAU**
Mortgage	$25,920	$9,720	-	$9,720
Energy	$500	$14,000	$500	$14,000
O&M	$2,000	$3,500	$2,000	$3,500
Labor	$5,000	$5,000	$5,000	$5,000
Materials, Tax	$4,400	$4,400	$4,400	$4,400
Total Expenses	$37,820	$36,620	$11,900	$36,62 0
Income	$55,000	$42,000	$55,000	$42,000
NET	$17,180	$5,380	$43,100	$5,380

MODELING / DESIGN SPECS

- ❖ The best model would be a finite-element simulation
- ❖ Time and resource limitations led to a "thermal circuit" approach; similar to MATLAB Simulink building models
- ❖ Each section of the building's envelope is described by successive layers of construction materials; compute conductance and time constant
- ❖ Interior air temperature transient response to selected inputs

MODELING / DESIGN SPECS



LEGEND

Text = exterior dry bulb ambient air temperature

ΔText solar gain_k = increment of exterior temperature of the kth envelope section due to insolation, excluding windows

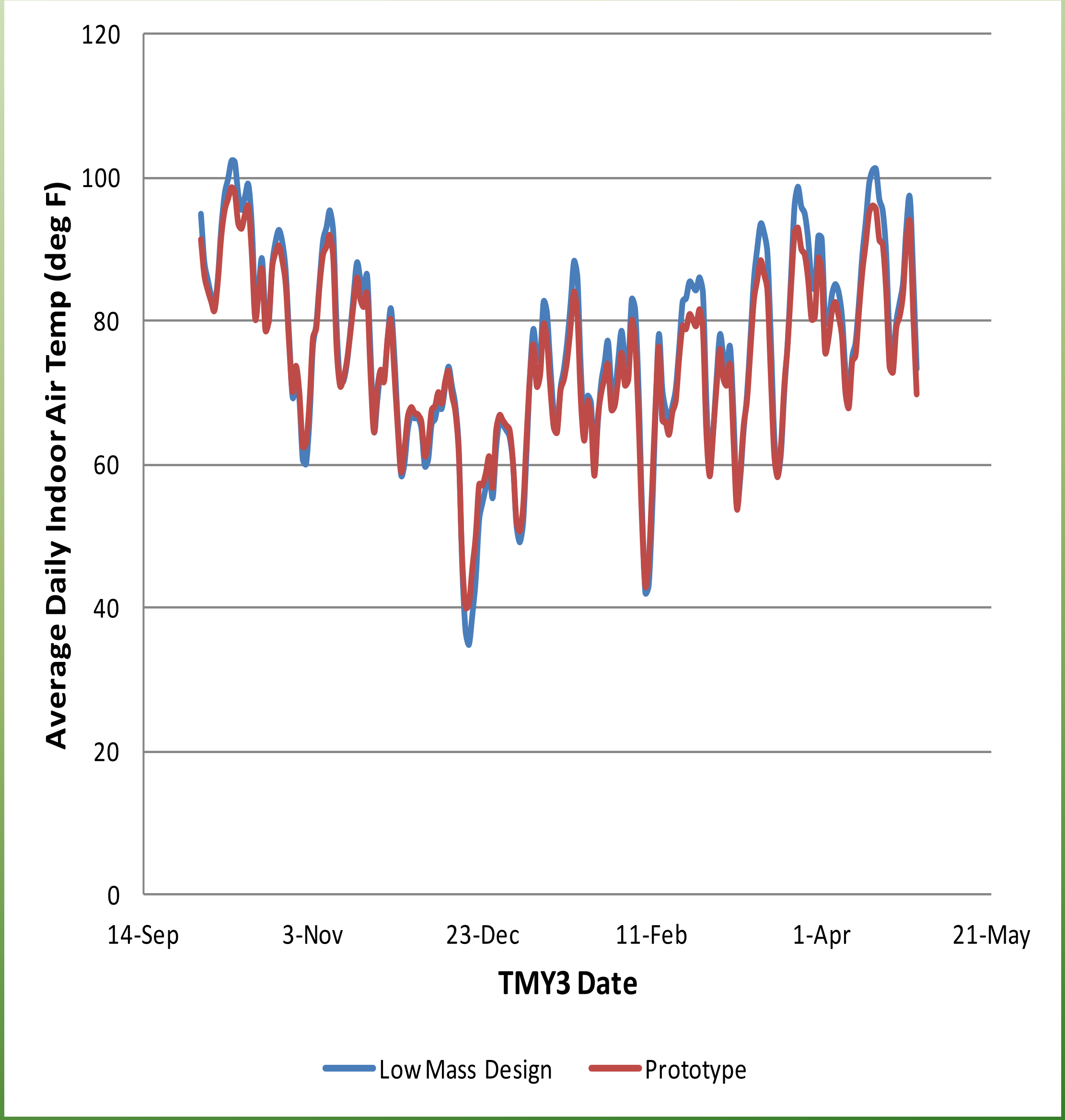
f(τ_k) = a function of the time constant (τ) of the thermal mass of each of the k envelope sections; "absorption parameters" are for calculation of interior solar heat gain of the section

Tint = interior air temperature including gains through non-window areas of the envelope

ΔTint solar gain = total contribution of interior solar gains excluding storage mass contributions

Tnet int = net interior air temperature; output of the model

MODELING / DESIGN SPECS



Shown at left is a graph of the results of the first design simulation using the model.

The demo prototype included substantial thermal mass in its north wall. The question arose as to whether this mass was necessary for the observed thermal performance.

The simulation suggested that the extra mass mostly prevented some slight average temperature swings in the mid- to late winter.

The next generation designs accordingly excluded the extra mass, thereby reducing construction costs.

Ongoing monitoring has validated the thermal performance predicted by the model.

SE elevation of a second-generation design using less installed thermal mass than the demo prototype. This 3,000 sq ft structure was commissioned by the Sushi Den group of restaurants in the Denver CO area. They grow a wide variety of vegetables year-round while imposing a miniscule carbon footprint.

TECH TRANSFER

- The Green Greenhouse relies on solar energy for both lighting and heating. The energy performance of the greenhouse will thus vary according to regional solar availability.

- Colorado has cold but sunny winters; places like New York have the cold but not as much sun

- Energy requirements for heating, lighting, ventilation, etc are likely to vary by region and by crop selection

- A worthy goal would be to take the lessons learned in Colorado and transfer them to regions like the Northeast US

- Develop the simulation model into a design tool and field-test in local demonstration projects

- The next several slides describe the players needed

TECH TRANSFER: Architect

- Interpret the design and produce construction documents

- Site assessments (surveying, permits, etc)

- Detailed energy analysis (or access to a building energy analyst); specification of all electrical, mechanical, water systems

- Code compliance and stamping of construction drawings

- Work with the owner on aesthetic details

- Develop standardized starting templates for a region

- Assist with grants, utility programs, etc

- This is a potential specialty niche for an architect

TECH TRANSFER: General Contractor

- Construction management
- Pricing and materials selection
- Hire and oversee subcontractors
- Assist with commissioning of the greenhouse
- The best arrangement would be a contractor that has “everything under one roof”
- Someone to be there should issues arise / warranty agreement
- Knowledge of state-of-the-art energy products and services

TECH TRANSFER: Financing

- Pre-supposes that (a) there is a reasonable payback to the project, and (b) there is a demonstrated demand for the technology

- Requires an institution that has worked with or is at least familiar with the building energy industry; example: energy-efficient mortgages

- The financier should provide a turn-key package; this is perhaps the most difficult aspect to set up

- Understanding of the US and State Departments of Agriculture, small business loans for farming operations, etc

- Preferably familiar with the other team members' businesses

- Possible extension of existing co-ops, credit unions and other local-friendly institutions

TECH TRANSFER: Ownership Models

- Private commercial farmer; organic, permaculture, etc
- Community ownership / co-op
- Builder or franchise ownership with a lease to the user (a “planting purchase agreement”)
- Small units can be built as additions to existing structures like private residences and treated as expansions or improvements
- Rooftop construction on existing structures like warehouses or factories – second income from otherwise unused space
- Partnership arrangements with specialty growers like florists, aquaculture companies, etc
- Restaurants, distributors, and other food industry businesses that want to own and control production of their wares

TECH TRANSFER: Putting It All Together

- Regional demonstration projects of the design and its associated technology

- Needs entrepreneurs who can put the team together (especially for financing options)

- Design software and monitoring services; a great opportunity to create applications for commercial use

- A natural extension for a company with building experience that installs solar electric and thermal systems

- Consultation with Synergistic Building Technologies, especially for automated insulating shutters

- Networking, networking, networking

We'd Like to Hear from You!

Feedback, comments, suggestions, questions --

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The principal references for this presentation are:
Michael R. Stiles, "A Design Model of Transient Temperature Performance for a Green Greenhouse," Distributed Generation and Alternative Energy Journal, Spring 2012 Vol. 27, No. 2, pgs 56-76

Larry Kinney, John Hutson, Michael Stiles and Gardner Clute, "Energy-Efficient Greenhouse Breakthrough," Proceeding of the American Council for an Energy Efficient Economy 2012 Summer Study on Energy Efficiency in Buildings, August 2012
http://aceee.org/files/proceedings/2012/start.htm
(search the web page for the title; the paper is available on-line)