Energy Efficient Greenhouse Design

Tom Manning
New Jersey Agricultural Experiment Station

Principles of Energy Efficiency and Conservation

- Understand the problem (audits and monitoring)
- Use functional and efficient controls
- Size equipment and structures appropriately
- Share resources
- Maintain equipment and facilities
- Increase production
- Pick good sites
- Use efficient architecture
- Adopt efficient technologies
- Insulate

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Energy savings strategies and systems

- Measure ("If you cannot measure it, you cannot improve it")
- Temperature integration (correlated with DLI)
- Integrated Light, Temp, RH and CO2 control
- Double (triple) layer glazing
- Energy/shade curtains
- Floor heating
- Condensing boilers
- Variable speed motors and pumps
- Heat pumps with energy buffering and/or long-term storage

Both et al. 2007. Evaluating energy savings strategies using heat pumps and energy storage for greenhouses. ASABE paper 074011. ASABE, 2950 Niles Road, St. Joseph, MI 49085-9659.

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Advantages of Automated Control Systems

- Data monitoring and trending
- Alarm capability
- Maintenance scheduling
- More complex control at all times

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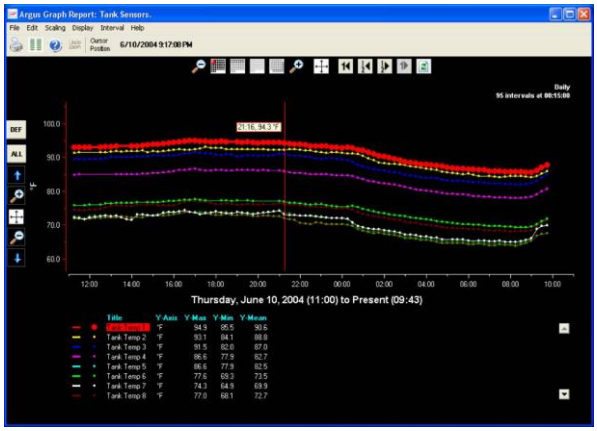

High Tunnels

Both et al. 2007. Evaluation of a manual energy curtain for tomato production in high tunnels. HortTechnology 17(4):467-472.

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Gutter Connected Greenhouses

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Perimeter Insulation

- At least 1 foot deep (preferably 2 feet)
- At least 1 inch thick (preferably 2 inches)

- Avoid gaps
- Try to work neatly around post footings

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Thermal/Shade Curtains

Courtesy Sion Orchids

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North facing side wall insulation

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Rollup fan housing curtain

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Hot Air Furnace – Point Source

Cheap but inefficient

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Distributed Hot Air

More efficient and uniform

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New Unit Heaters

- Direct-fired (no heat exchanger)
- 99% efficient
- Natural gas or propane
- Very low CO and NOx production
- Some have outside air-intake
- Various safety features
- CO2 enrichment

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Hot Water

Even more efficient and uniform

Modulated temperature better than ON/OFF

Three-way valve

Four-way valves and Circulator

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New Boiler Technology

- Condensing boilers (95-98% efficient):
- *Made of stainless steel, allowing condensation of water vapor produced during combustion (producing more heat), and equipped with a heat exchanger to pre-heat the boiler water with heat from combustion gasses*
  - Low mass (boiler components and water)
  - Operated on demand (no stand-by losses)
  - Heat delivery in minutes
  - Small foot-print
  - Low maintenance
  - *Can be combined with high mass boilers*

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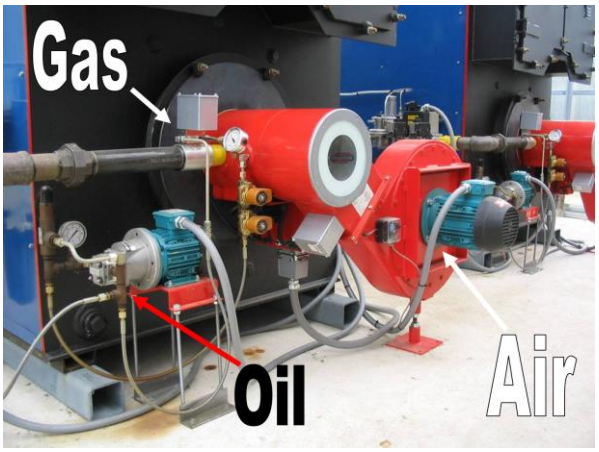
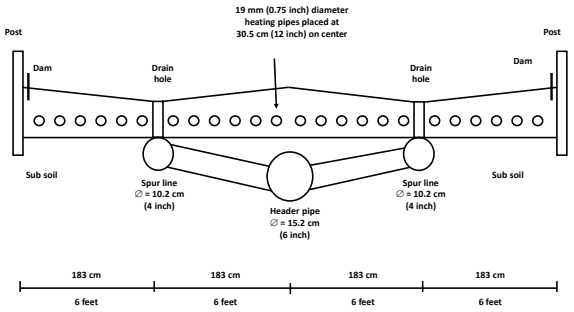
- Dual fuel boiler (natural gas & fuel oil)



Floor Heating



Bench Heating

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Greenhouse Ventilation

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Heating and Cooling

- *Insulate heated and cooled spaces.*
- *Use strip doors & dock seals where appropriate.*
- *Use high efficiency boilers, furnaces and cooling equipment.*
- *Maintain boilers, filters, steam systems, etc.*
- *Run heating and cooling systems only as needed.*
- *Use multiple appropriately sized units (boilers, compressors, etc.)*
- *Install radiant heat.*
- *Automate greenhouse controls.*

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Efficient Use of Supplemental Lighting

- *Schedule for off-peak hours.*
- *Stagger lighting schedules to minimize peak loads.*
- *Arrange lights in accordance with manufacturer's recommendations.*
- *Optimize lighting strategies*
- *Use efficient fixtures*

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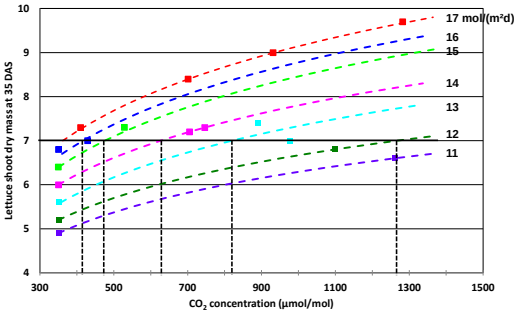
Trading Supplemental Light for CO_2 Enrichment



Both, A.J., L.D. Albright, and R.W. Langhans. 1998. Coordinated management of daily PAR integral and carbon dioxide for hydroponic lettuce production. Acta Hort 456:45-51.

Greenhouse Water Use

- *Recirculation systems*
  - *Water Treatment*
- *Recovery of plant transpiration*
  - *Condensation*
- *Rainwater collection and use*
  - *Groundwater recharge concerns*
- *Lettuce: 2.75g of dry mass per liter of water*

Reducing Energy Costs

- Use an energy/shade curtain (20-30%)
- Consider high efficiency heaters/boilers (20-40%)
- Oil: install a flame retention burner (15-20%)*
- Consider a dual fuel system
- Use computer control and variable speed motors and pumps (5-10%)
- Use "natural" ramping (2-5%)
- Keep track of energy use
- Lower heating system temperature (5-10%)

**results in better mixing of fuel and combustion air*

Reducing Energy Costs - Continued

- Use highest R-value for insulation (2-5%)
- Provide a wind barrier (don't block light; 2-5%)
- Perform timely maintenance (5-10%)
- Check greenhouse for leaks (2-5%):
- Caulk and weatherstrip doors, windows, etc.
- Repair misaligned ventilation shutters
- Seal all cracks in walls
- Repair broken glazing
- Select the cheapest fuel supplier (2-5%)

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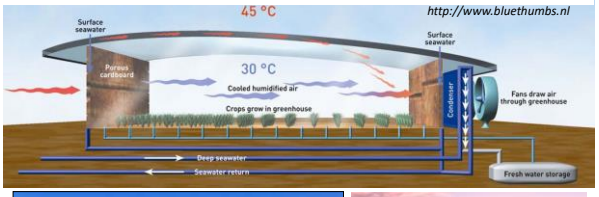
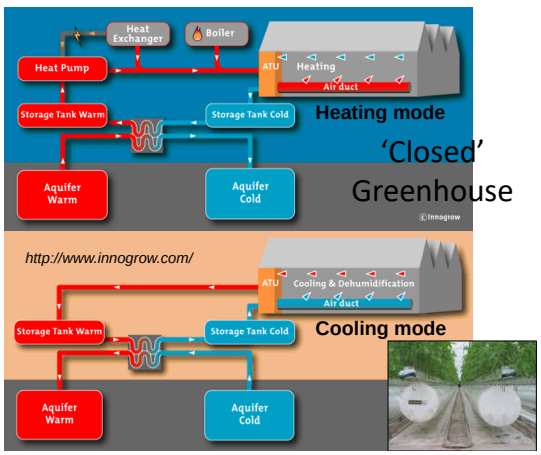
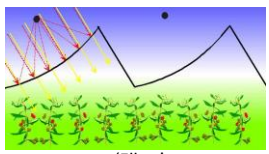
Seawater Greenhouse



Sundrop Farms, Port Augusta, AUS



Energy Producing Greenhouses



'Elkas'

Dr. Piet Sonneveld, Wageningen University

Fresnel greenhouse

Renewable and Alternative Energy

- ✓ *Always improve efficiency first.*
- ✓ *Check that any new source of energy is suited for your specific location and conditions.*
- ✓ *Understand the performance potential of renewable and alternative technologies without incentives.*

Alternative Energy Options

- Wind
- Solar (electricity and/or heat)
- Biomass
- Waste heat from industry and power stations
- Ground source or geothermal
- Reciprocating engines and (micro)turbines (CHP)
  - natural gas
  - landfill gas (gas purification required)
  - digester gas (gas purification required)
- Hydropower

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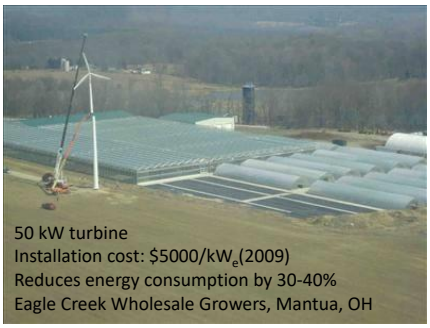
- Wind



50 kW turbine
Installation cost: $5000/$kW_e$(2009)
Reduces energy consumption by 30-40%
Eagle Creek Wholesale Growers, Mantua, OH

http://www.greenhousegrower.com

- Land based and floating solar panels at a vineyard in Oakville, CA $8,805/$kW_e$

http://www.nytimes.com

- Photovoltaic film incorporated in the glazing

Cost: €4600 per installed kW_e (Naples, Italy)
Manufacturer: Sun Well Solar, Taiwan

http://www.freshplaza.com

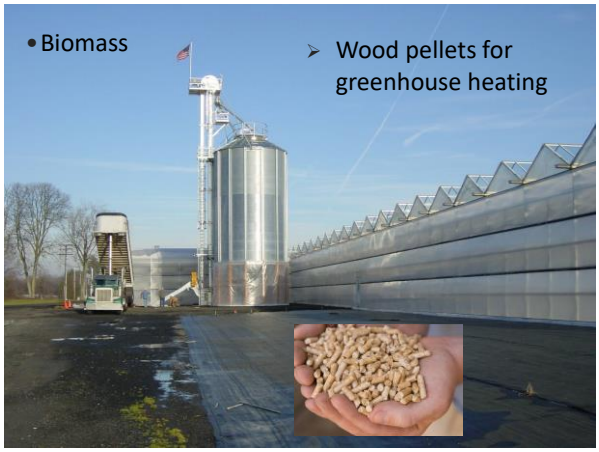
- Solar Thermal
  - 11,000 square feet of collectors for 58,000 square feet of greenhouse

- *Switchgrass*

- 5,000 kW_{th} biomass boiler (for almost 3 ha of GH)

Installation cost:
$140/$kW_{th}$, including silos

- Biomass
  - Wood pellets for greenhouse heating

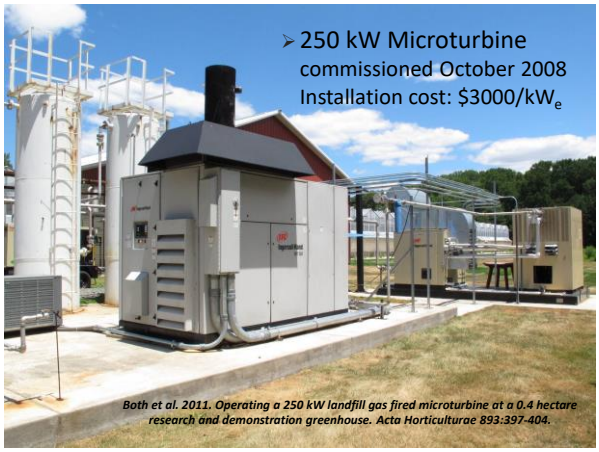


- Burning wood

Waste Heat

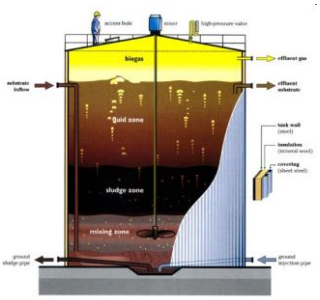
Combined Heat and Power

In the Netherlands in 2010, ~12% (3 GW) of the national electricity consumption was produced by CHP units installed at greenhouse operations (operated on natural gas)



Both et al. 2011. Operating a 250 kW landfill gas fired microturbine at a 0.4 hectare research and demonstration greenhouse. Acta Horticulturae 893:397-404.

Anaerobic Digester



http://home.comcast.net/~hollywastewater/Process.htm

Thank You…

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