Energy-Efficiency in Greenhouse Crop Production

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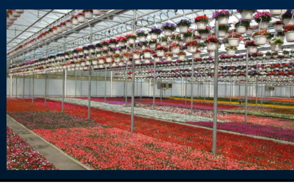

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Energy Efficiency in Greenhouse Crop Production

INTRODUCTION

- The majority of bedding plants are produced in the U.S. in heated greenhouses from January to May
- In the northern U.S., energy for heating represents 10% to 15% of the total greenhouse production cost (Bartok, 2001)

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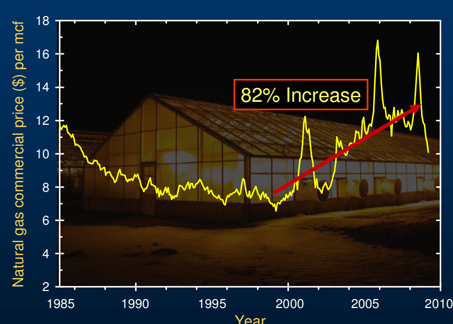
Recent Surge in Fuel Costs



Source: Energy Information Administration, 2009

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Energy Efficiency in Greenhouse Crop Production

INTRODUCTION

- The increase and fluctuation in fuel prices has threatened the profitability of the greenhouse industry in the upper Midwest.
- One strategy to cope with higher energy prices is to improve production efficiency and minimize energy inputs.

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Energy Efficiency in Greenhouse Crop Production

Outline

- Using supplemental lighting on plugs and transplants to accelerate cropping
- Controlling photoperiod for rapid flowering of finish plants
- Energy-efficient temperature strategies during the finish stage

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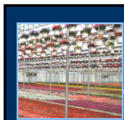

Energy Efficiency in Greenhouse Crop Production

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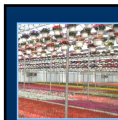

Lighting Plugs and Transplants

Light Consists of Three Dimensions

1. Light quantity (intensity) ⟶ photosynthesis
2. Light quality (distribution) ⟶ stem extension
3. Light duration (photoperiod) ⟶ flowering

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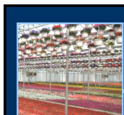

Lighting Plugs and Transplants

Light Quantity

- Growth and yield of most crops is determined by the cumulative amount of light received over time
- Term daily light integral (DLI) describes this cumulative amount of light
- DLI is normally expressed in units of mols of photons per square meter and day (mol·m^{-2}·d^{-1})

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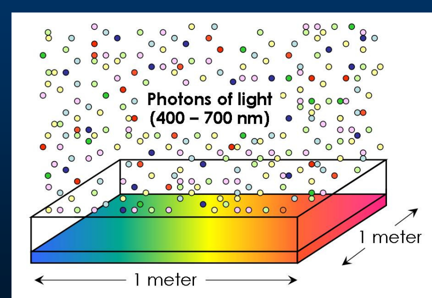
Light Quantity



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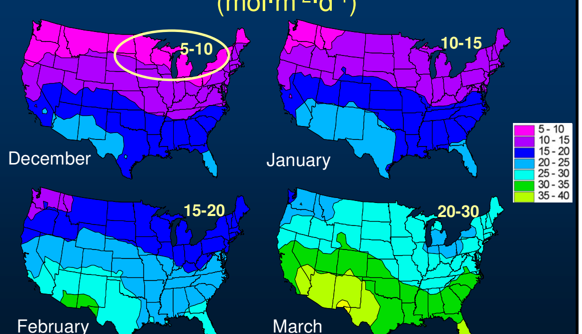
Average Outdoor Daily Light Integral (mol·m^{-2}·d^{-1})



Jim Faust, Clemson University

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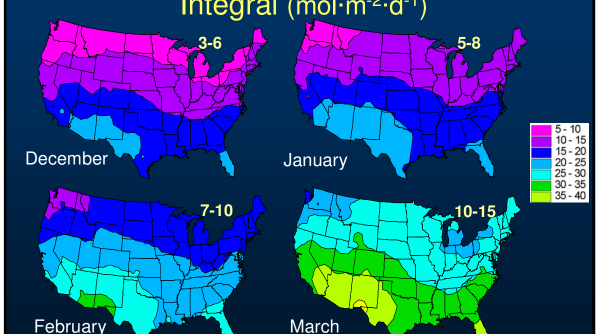
Average Greenhouse Daily Light Integral (mol·m^{-2}·d^{-1})



Maps available online at www.hrt.msu.edu/floraoe/productioninfo.htm

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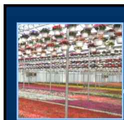


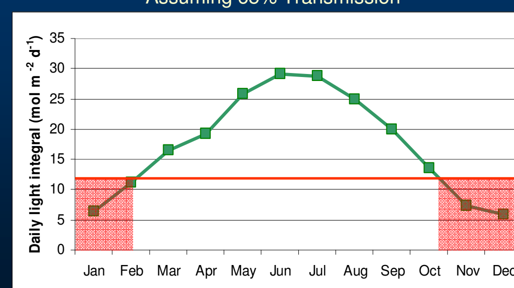
Lighting Plugs and Transplants

Factors that influence DLI in greenhouses:

- Time of the year (sun's angle)
- Location (latitude)
- − Cloud cover
- − Greenhouse glazing
- − Whitewash or shade curtains
- − Structure and obstructions (incl. plants)
- + Supplemental lighting

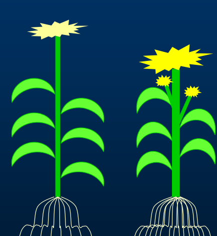
Average Daily Light Integral Inside a Greenhouse in the Midwest

Assuming 65% Transmission



Plant Responses to Daily Light Integral:

- Leaves (smaller and thicker)
- Flowers (more and larger)
- Time to flower (faster, due partly to temperature)
- Branching (increased)
- Stem diameter (increased)
- Root growth (increased)



Petunia Tiny Tunia 'Violet Ice'

16 Days after stick

Average DLI (mol·m^{-2}·d^{-1}):

1.6 2.8 5.4 8.4

DLI ($mol \cdot m^{-2} \cdot d^{-1}$): 4 7 14

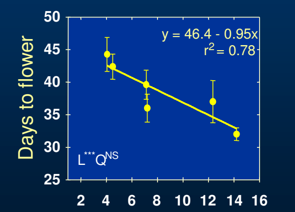
Celosia

Marigold

Effect of DLI on Subsequent Flowering

Celosia 'Gloria Mix'

Common environment: 72 °F and DLI of 8.5 $mol \cdot m^{-2} \cdot d^{-1}$

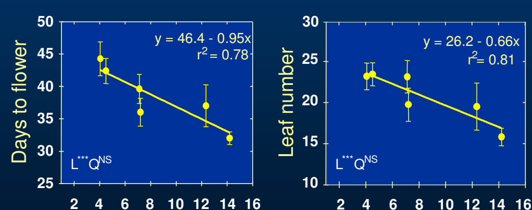


Daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$) during seeding stage

Effect of DLI on Subsequent Flowering

Celosia 'Gloria Mix'

Common environment: 72 °F and DLI of 8.5 $mol \cdot m^{-2} \cdot d^{-1}$



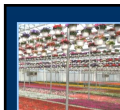
Daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$) during seeding stage

Advantages of HPS Lighting During the Seedling Stage

- Increased dry mass (higher quality)
- Greater root mass
  - More "pullable" plug for transplanting
- Heat from lamps
  - Increases rate of development
  - Reduces finish crop time
- Carryover effects after transplant

Supplemental Lighting Guidelines

- Instantaneous light intensity and lighting duration are both important; both determine the DLI provided to plants
- The high-pressure sodium (HPS) lamp is the most efficient lamp type
- Goal is to provide 300 to 600 footcandles of supplemental lighting at plant level (400 to 500 footcandles is typical)
- Lamps are typically operated up to 18 hours on cloudy days, and are turned off when sunny.
- Benefit of supplemental lighting is greatest from October through March. Most growers turn off lamps in April.



Energy Efficiency in Greenhouse Crop Production

Outline

- Using supplemental lighting on plugs and transplants to accelerate cropping
- **Controlling photoperiod for rapid flowering of finish plants**
- Energy-efficient temperature strategies during the finish stage

Controlling Photoperiod for Rapid Flowering of Finish Plants

- Flowering in many greenhouse crops is regulated by photoperiod
- The production time of photoperiodic plants is influenced (positively or negatively) by the photoperiod that is provided to plants
- Therefore, by providing the appropriate photoperiod to plants, production time can be optimized

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Controlling Photoperiod for Rapid Flowering of Finish Plants

Most crops have one of five flowering responses to photoperiod:

- Obligate short day
- Facultative short day
- Day-neutral
- Obligate long day
- Facultative long day

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Controlling Photoperiod for Rapid Flowering of Finish Plants

Obligate Short-Day Plants

- Plants only flower under a short photoperiod, usually 12 hours or less

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Pot mum 'Auburn'

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Controlling Photoperiod for Rapid Flowering of Finish Plants

Facultative Short-Day Plants

- Plants flower earlier under a short photoperiod than under a long photoperiod

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Effect of Photoperiod on Growth And Flowering of Dahlia

Photoperiod (hours):					
10	12	14	16	24	4-h night interruption

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Zinnia

40 Days after transplant at 68/61 °F (Day/night)

Ambient **380 fc** **760 fc** **1140 fc**

Photo courtesy Univ. of Minnesota

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Bedding Plant Responses to Photoperiod

Short-day plants

African marigold (F or O)
Cosmos (F)
Dahlia (F)
Morning glory (F)
Salvia (F)
Zinnia (F, some cvs.)

F = facultative response
O = obligate response

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Controlling Photoperiod for Rapid Flowering of Finish Plants

Day-Neutral Plants

- Plants are insensitive to photoperiod and flower at the same time under short or long days

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Impatiens 'Super Elfin Lipstick'

56 Days after transplant at 68/61 °F (Day/night)

Photo courtesy Univ. of Minnesota

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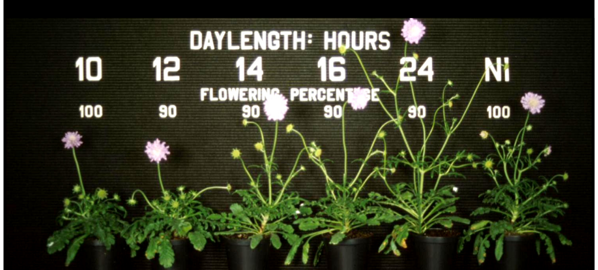
Scabiosa columbaria 'Butterfly Blue'

15 Weeks at 41 °F

4 weeks after transplant at 68 °F



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Bedding Plant Responses to Photoperiod

Short-day plants	Day-neutral plants
African marigold (F or O)	Cleome
Cosmos (F)	French marigold
Dahlia (F)	Geranium
Morning glory (F)	Impatiens
Salvia (F)	N.G. impatiens
Zinnia (F, some cvs.)	Thunbergia
	Tomato
	Vinca
	Wax begonia
	Zinnia (some cvs.)

F = facultative response
O = obligate response

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Controlling Photoperiod for Rapid Flowering of Finish Plants

Obligate Long-day Plants

- Plants only flower under a long photoperiod, often 14 hours or more

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Rudbeckia fulgida 'Goldstrum'

No Cold 16 Weeks forcing at 68 °F

Photoperiod (hours):	10	12	13	14	16	24	NI
Flowering percentage	0	0	0	100	90	90	90

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Petunia 'Wave Purple'

98 Days after transplant at 68/61 °F (Day/night)

Photo courtesy Univ. of Minnesota

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Controlling Photoperiod for Rapid Flowering of Finish Plants

Facultative Long-day Plants

- Plants flower earlier under a long photoperiod than under a short photoperiod

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Bedding Plant Responses to Photoperiod

Short-day plants	Day-neutral plants	Long-day plants
African marigold (F or O)	Cleome	Ageratum (F)
Cosmos (F)	French marigold	Blue salvia (F)
Dahlia (F)	Geranium	Dianthus (F)
Morning glory (F)	Impatiens	Fuchsia (F or O)
Salvia (F)	N.G. impatiens	Gazania (F or O)
Zinnia (F, some cvs.)	Thunbergia	Lobelia (blue) (F or O)
	Tomato	Pansy (F)
	Vinca	Petunia (F or O)
	Wax begonia	Rudbeckia (O)
	Zinnia (some cvs.)	Snapdragon (F)
		Strawflower (O)
		Sunflower (F)
		Tuberous begonia (O)
		Verbena (F)

F = facultative response
O = obligate response

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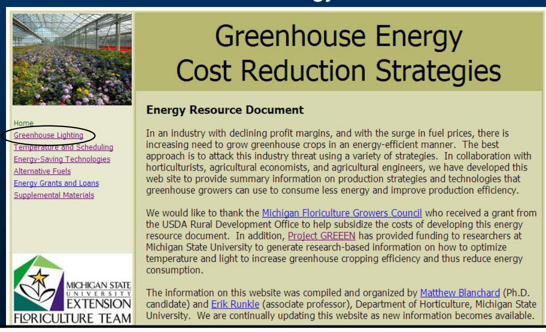
A list of the photoperiod requirements for annuals and perennials can be found at:

www.hrt.msu.edu/energy/Notebook.htm



Greenhouse Energy
Cost Reduction Strategies

Home
Greenhouse Lighting
Temperature and Scheduling
Energy-Saving Technologies
Alternative Fuels
Energy Grants and Loans
Supplemental Materials

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Energy Resource Document

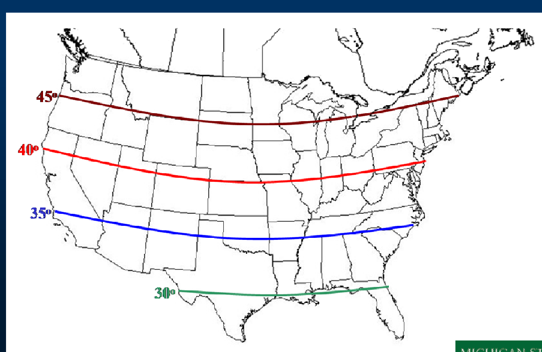
In an industry with declining profit margins, and with the surge in fuel prices, there is increasing need to grow greenhouse crops in an energy-efficient manner. The best approach is to attack this industry threat using a variety of strategies. In collaboration with horticulturists, agricultural economists, and agricultural engineers, we have developed this web site to provide summary information on production strategies and technologies that greenhouse growers can use to consume less energy and improve production efficiency.

We would like to thank the Michigan Floriculture Growers Council who received a grant from the USDA Rural Development Office to help subsidize the costs of developing this energy resource document. In addition, Project GREEEN has provided funding to researchers at Michigan State University to generate research-based information on how to optimize temperature and light to increase greenhouse cropping efficiency and thus reduce energy consumption.

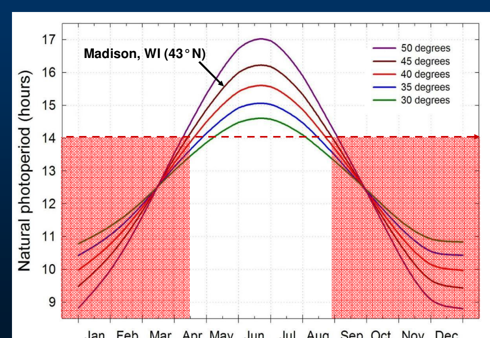
The information on this website was compiled and organized by Matthew Blanchard (Ph.D. candidate) and Erik Runkle (associate professor), Department of Horticulture, Michigan State University. We are continually updating this website as new information becomes available.

Manipulating Photoperiod

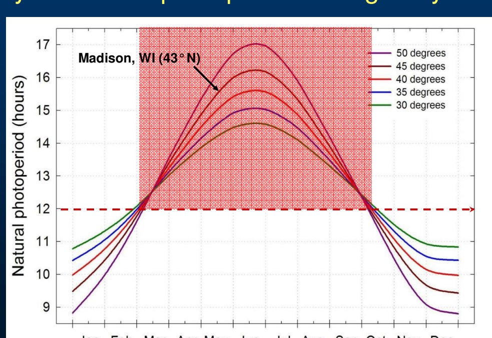
Determine the latitude of your location

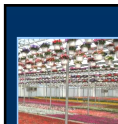


Use this graph to determine your natural photoperiod during the year



Use this graph to determine your natural photoperiod during the year

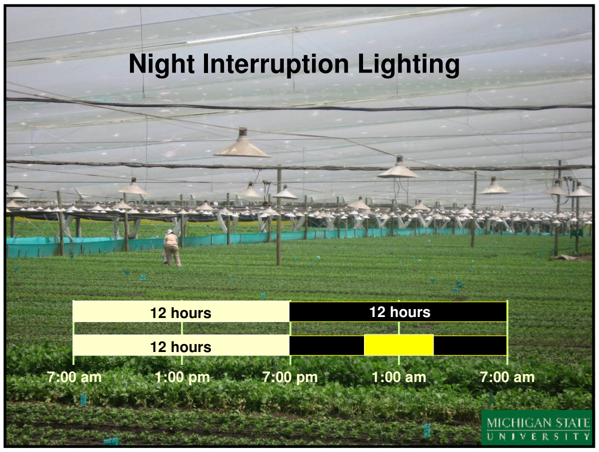


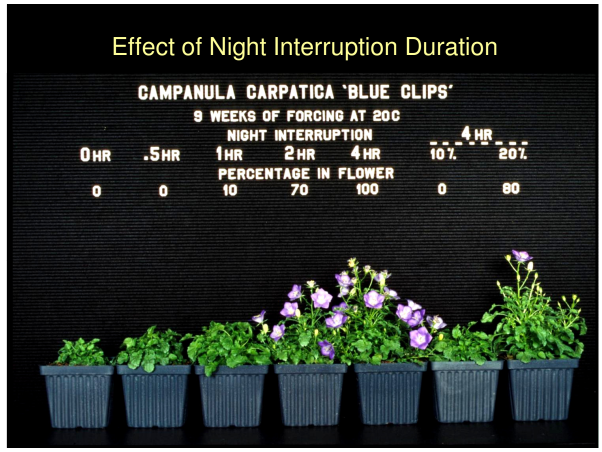


Controlling Photoperiod for Rapid Flowering of Finish Plants

Creating Long Days

- Incandescent night break
- Day-extension
- Supplemental high-pressure sodium (HPS) lamps
- Cyclic lighting (Boom lighting, Beamflicker, or incandescent lamps)





Controlling Photoperiod for Rapid Flowering of Finish Plants

Incandescent Lamps

Advantages

- Compact light source
- Low initial installation cost
- Bulb life is not affected by number of starts (good for cyclic lighting)
- Most commonly used for photoperiodic lighting

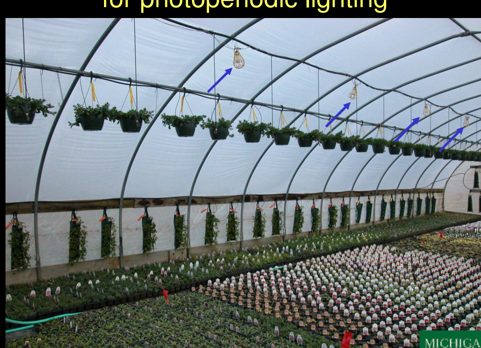
Controlling Photoperiod for Rapid Flowering of Finish Plants

Incandescent Lamps

Disadvantages

- Low light output per input watt of electricity (not energy efficient)
- Requires heavy wiring installation for amount of light
- Low red-to-far-red ratio promotes stem elongation

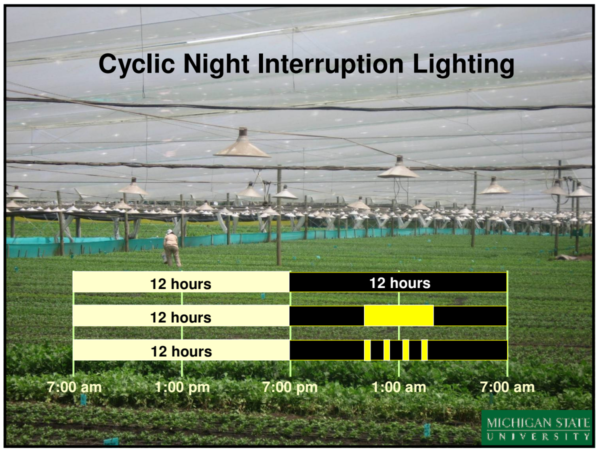
Simple installation of incandescent lamps for photoperiodic lighting



Controlling Photoperiod for Rapid Flowering of Finish Plants

Night Interruption Lighting

- Night-break lamps can be cycled on for 6 minutes and off for 24 minutes to reduce costs and electrical load. This is termed “cyclical lighting”.



Controlling Photoperiod for Rapid Flowering of Finish Plants

Cyclic Night Interruption Lighting

- Night-break lamps can be cycled on for 6 minutes and off for 24 minutes to reduce costs and electrical load. This is termed “cyclical lighting”.
- Cyclical night-break lighting is used to inhibit flowering of short-day plants, and is effective at inducing flowering of some long-day plants.
- Continuous night-break lighting is usually applied to long-day plants as “insurance” for a strong response.

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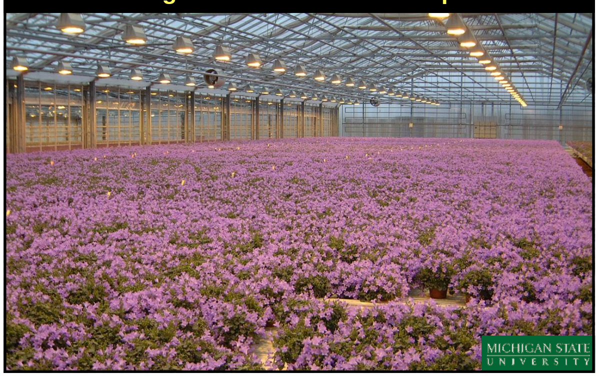
Long-Day Lighting with Fixed High-Pressure Sodium Lamps



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High-Pressure Sodium Lamps on Moving Boom

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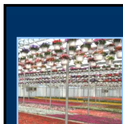

Controlling Photoperiod for Rapid Flowering of Finish Plants

Beamflicker

- Stationary high-pressure sodium lamp with an oscillating parabolic reflector
- Reflector rotates 180° to provide an intermittent beam of light over a relatively large growing area

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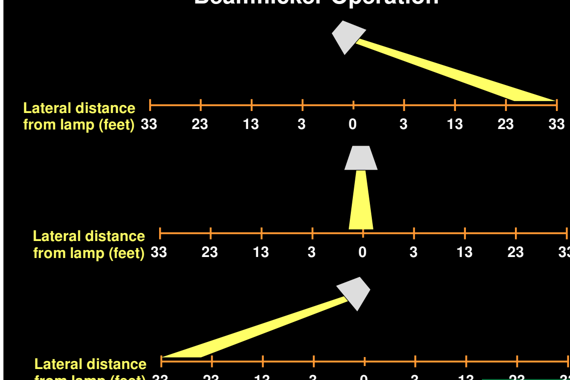
Beamflicker Operation



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Petunia 'Dreams Neon Rose'

4-Hour night interruption

6 weeks after transplant at 68 °F

600-Watt Beamflicker
Distance from lamp (ft):

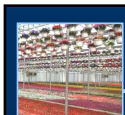
9-hour short day	60-Watt INC	3	13	23	33	43

Days to flower relative to INC

+9	0	+4	+3	+6	+5	+8

Controlling Photoperiod for Rapid Flowering of Finish Plants

- Provide at least 10 foot-candles to bedding plants and perennials that are long-day plants
- Light until around April 15, when the days become naturally long
- In general, provide long days to plugs during the last two weeks, and to finish plants until flower buds are visible (or longer for obligate long-day plants)



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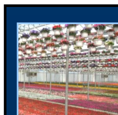
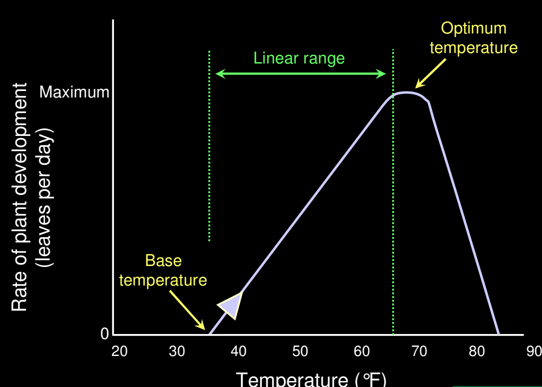
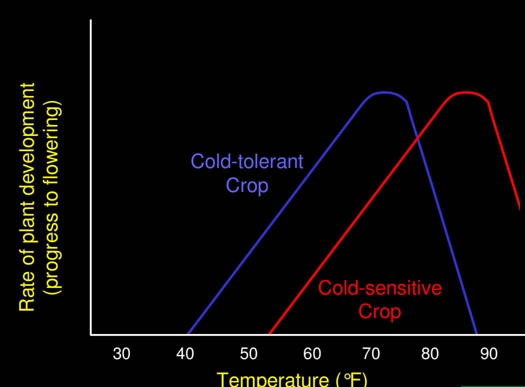


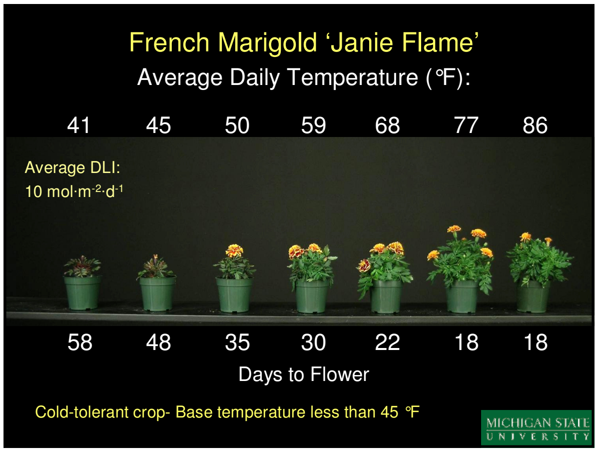
Energy Efficiency in Greenhouse Crop Production

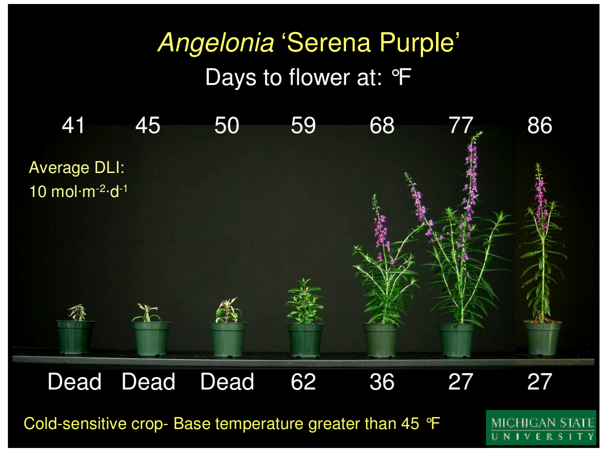
Time to flower can be influenced by:

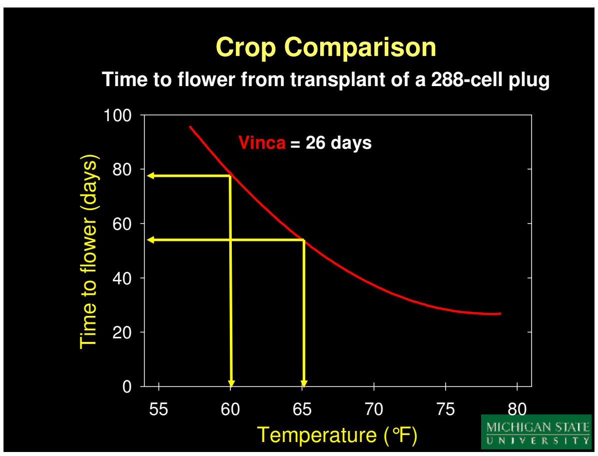
- Plant maturity
- Photoperiod
- Vernalization
- Average daily temperature
- Daily light integral

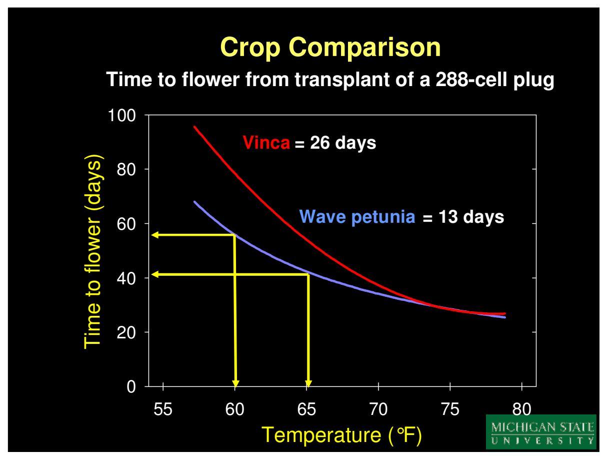


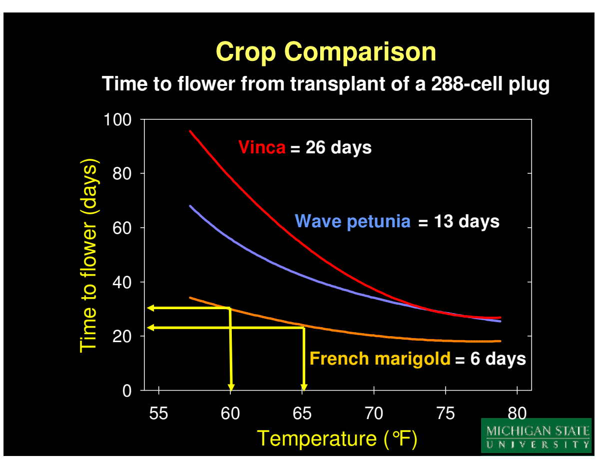












Cold-Tolerant Crops
(Base temperature <40 °F)

- Alyssum
- Campanula
- Cineraria
- Cyclamen
- Dianthus
- Dusty miller
- Easter lily
- Gaillardia
- Marigold (African, French)
- Nemesia
- Osteospermum
- Pansy
- Petunia 'Fantasy Blue', 'Dreams'
- Rudbeckia
- Scabiosa
- Schizanthus
- Shasta daisy
- Snapdragon
- Thanksgiving cactus
- Viola

Cold-Sensitive Crops
(Base temperature >45 °F)

- African violet
- Alocasia
- Angelonia
- Banana
- Begonia (fibrous)
- Browallia
- Caladium
- Canna
- Celosia
- Cleome
- Coleus
- Cosmos
- Hibiscus
- NG impatiens
- Pentas
- Pepper
- Petunia 'Easy Wave'
- Phalaenopsis orchid
- Poinsettia
- Portulaca
- Purple fountain grass
- Salvia (blue and red)
- Vinca
- Zinnia

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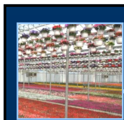


Energy Efficiency in Greenhouse Production

Temperature and DLI Interact to Control Growth and Flowering

- Temperature controls the rate of plant development
- DLI can influence:
  - Photosynthesis
  - Plant temperature
  - The leaf (node) number at which plants are induced to flower
- Precise scheduling requires temperature, photoperiod, and DLI inputs

Verbena 'Obsession Lilac'

37 days from transplant at (°F):

DLI:

5 mol·m⁻²·d⁻¹

	63	68	73	79
Days to flower from transplant	58	36	28	26
Flower number	9	8	7	6

13 mol·m⁻²·d⁻¹

	63	68	73	79
Days to flower from transplant	43	29	24	22
Flower number	14	13	12	10

African Marigold 'Antigua Primrose'

56 days from transplant at (°F):

DLI:

6 mol·m⁻²·d⁻¹

	57	63	68	73	79
Days to flower from transplant	79	69	59	49	39
Flower number	28	25	20	16	10

17 mol·m⁻²·d⁻¹

	57	63	68	73	79
Days to flower from transplant	64	58	52	46	40
Flower number	40	36	32	27	22

Petunia 'Wave Purple'

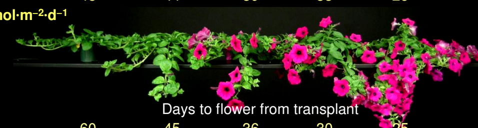
6 Weeks from transplant at (°F):

DLI:

5 mol·m⁻²·d⁻¹

	58	63	68	73	79
Days to flower from transplant	70	53	42	35	29
Flower bud number	48	44	39	33	25

16 mol·m⁻²·d⁻¹



	58	63	68	73	79
Days to flower from transplant	60	45	36	30	25
Flower bud number	74	69	64	59	51

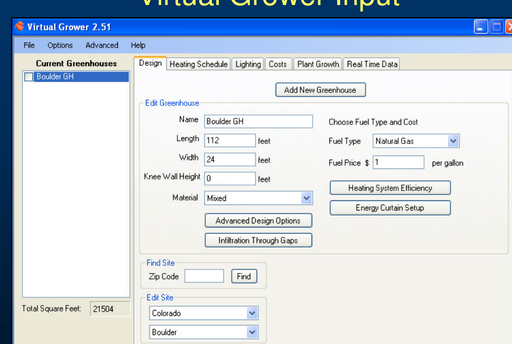
Estimating Greenhouse Heating Costs

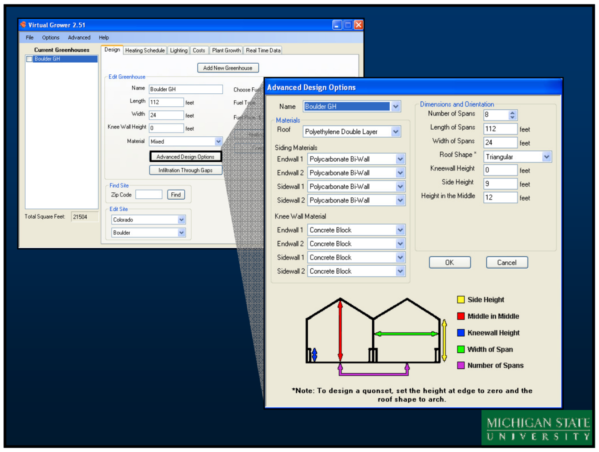
A software program developed by the USDA-ARS in Toledo, Ohio to estimate energy costs for greenhouse heating based on:

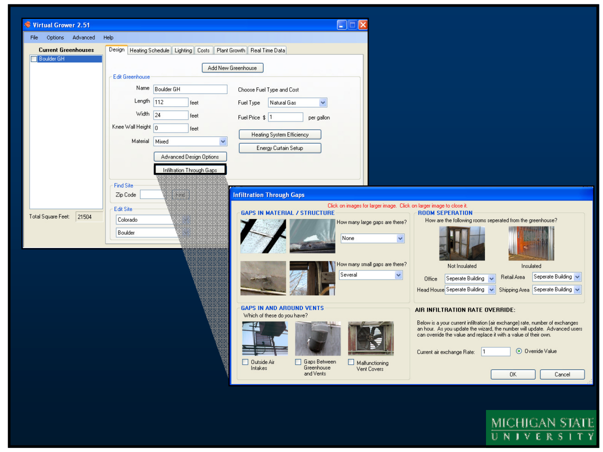
- Greenhouse location
- Time of year
- Greenhouse characteristics
- Energy type and cost
- Heating setpoints

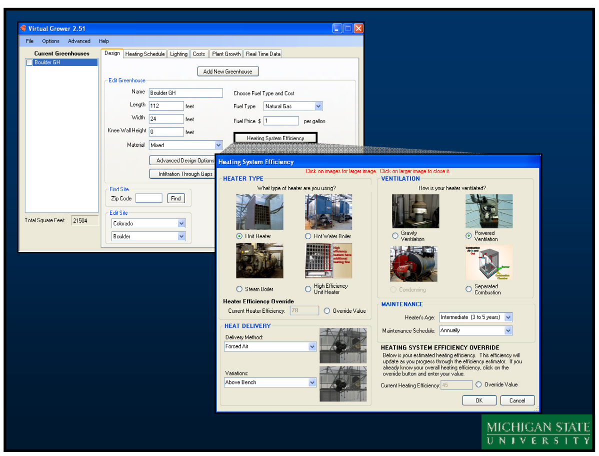
The Virtual Grower software is available free at: www.virtualgrower.net

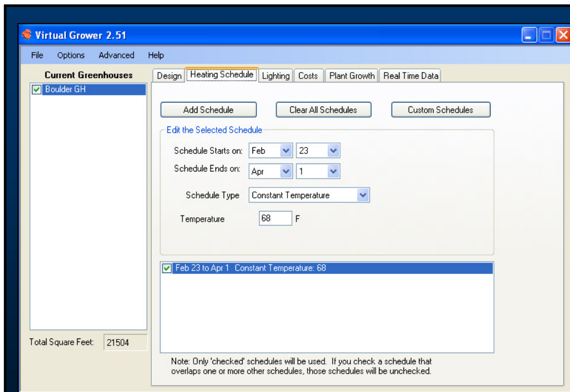
Virtual Grower Input



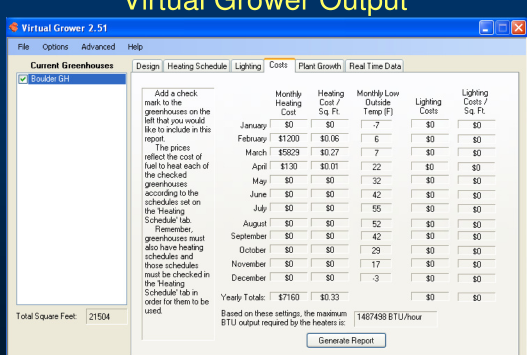








Virtual Grower Output



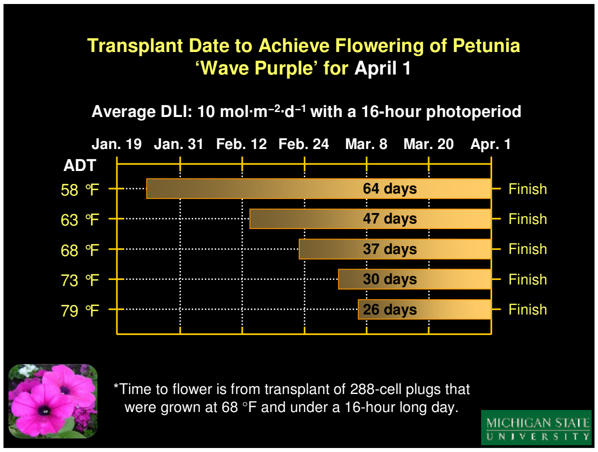
	Monthly Heating Cost	Heating Cost / Sq. Ft.	Monthly Low Outside Temp (F)	Lighting Costs	Lighting Costs / Sq. Ft.
January	$0	$0	-7	$0	$0
February	$1200	$0.06	6	$0	$0
March	$5829	$0.27	7	$0	$0
April	$130	$0.01	22	$0	$0
May	$0	$0	32	$0	$0
June	$0	$0	42	$0	$0
July	$0	$0	55	$0	$0
August	$0	$0	52	$0	$0
September	$0	$0	42	$0	$0
October	$0	$0	29	$0	$0
November	$0	$0	17	$0	$0
December	$0	$0	-3	$0	$0
Yearly Totals:	$7160	$0.33		$0	$0

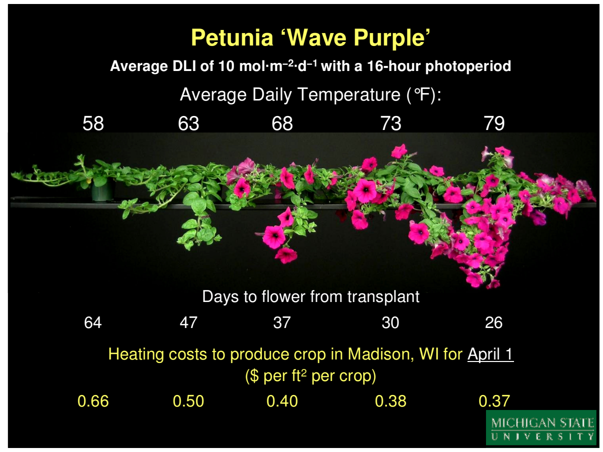
Greenhouse Heating Costs

- Heating costs were estimated to produce a petunia ‘Wave Purple’ crop at different temperatures and two finish dates in Madison, Wisconsin

Assumptions

- 21,504 ft^2 greenhouse with 8 spans each 112 × 24 ft
- Arched polyethylene double layer roof, 12 ft tall
- Gutter, 9 ft tall
- Polycarbonate bi-wall ends and sides
- Forced air unit heaters burning natural gas at $1.00 per therm ($10.24 MCF)
- 50% heater efficiency
- No energy curtain
- Hourly air infiltration rate of 1.0


Transplant Date to Achieve Flowering of Petunia 'Wave Purple' for April 1
Average DLI: 10 $mol \cdot m^{-2} \cdot d^{-1}$ with a 16-hour photoperiod
Jan. 19 Jan. 31 Feb. 12 Feb. 24 Mar. 8 Mar. 20 Apr. 1
ADT
58 °F 64 days Finish
63 °F 47 days Finish
68 °F 37 days Finish
73 °F 30 days Finish
79 °F 26 days Finish
*Time to flower is from transplant of 288-cell plugs that were grown at 68 °F and under a 16-hour long day.
MICHIGAN STATE UNIVERSITY


Petunia 'Wave Purple'
Average DLI of 10 $mol \cdot m^{-2} \cdot d^{-1}$ with a 16-hour photoperiod
Average Daily Temperature (°F):
58 63 68 73 79
Days to flower from transplant
64 47 37 30 26
Heating costs to produce crop in Madison, WI for April 1
($ per ft^2 per crop)
0.66 0.50 0.40 0.38 0.37
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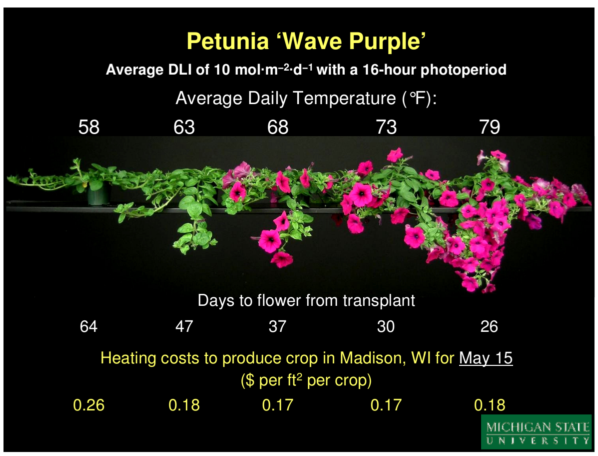
Petunia 'Wave Purple'
Average DLI of 10 $mol \cdot m^{-2} \cdot d^{-1}$ with a 16-hour photoperiod
Average Daily Temperature (°F):
58 63 68 73 79
Days to flower from transplant
64 47 37 30 26
Heating costs to produce crop in Madison, WI for May 15
($ per ft^2 per crop)
0.26 0.18 0.17 0.17 0.18
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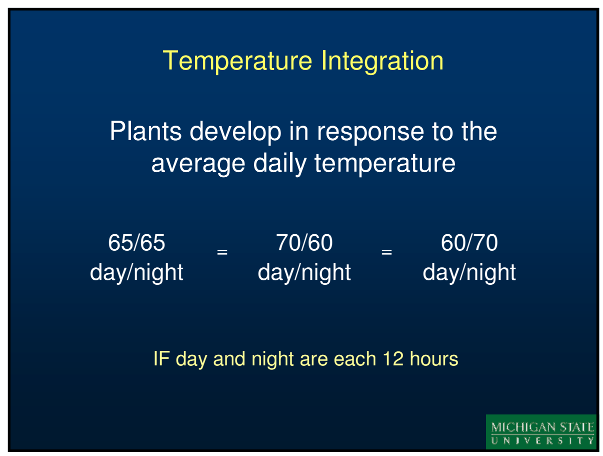
Temperature Integration
Plants develop in response to the average daily temperature
65/65 day/night = 70/60 day/night = 60/70 day/night
IF day and night are each 12 hours
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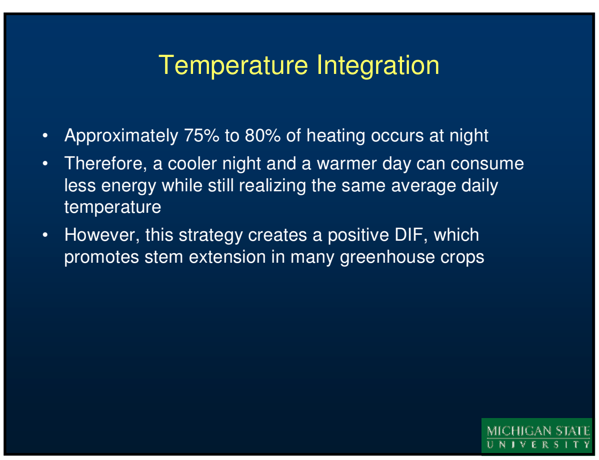
Temperature Integration
• Approximately 75% to 80% of heating occurs at night
• Therefore, a cooler night and a warmer day can consume less energy while still realizing the same average daily temperature
• However, this strategy creates a positive DIF, which promotes stem extension in many greenhouse crops
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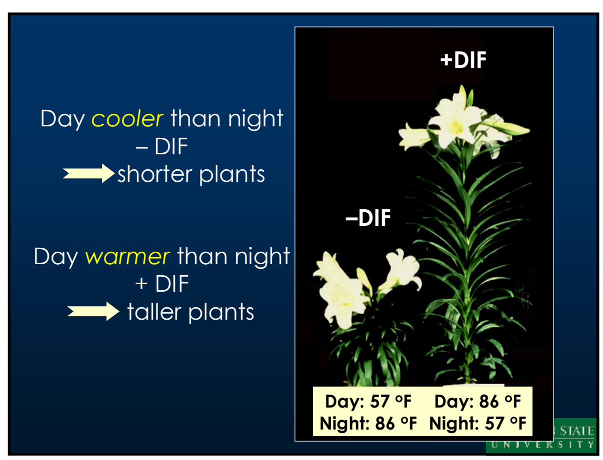
Day cooler than night
– DIF
shorter plants
Day warmer than night
+ DIF
taller plants
+DIF
–DIF
Day: 57 °F Night: 86 °F
Day: 86 °F Night: 57 °F

Estimated Heating Cost for a ½ Acre Greenhouse in Madison, WI to Maintain an Average 65 °F

Month	+10 °F DIF	0 °F DIF
January	$11,428	$11,435 (0%)
February	$8,158	$8,248 (+1%)
March	$5,983	$6,247 (+4%)
April	$2,868	$3,294 (+15%)

Assumptions:

- $10.29/mcf ($1.00/therm)
- Double poly greenhouse
- 8 spans, 112' x 24'
- Polycarbonate bi-wall ends & sides
- 50% heater efficiency
- Arched roof, 9' edge, 12' middle
- No curtain system
- Day 7:00am to 7:00pm

Based on data from Virtual Grower, USDA-ARS

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Estimated Heating Cost for a ½ Acre Greenhouse in Madison, WI to Maintain an Average 65 °F

Month	+10 °F DIF	0 °F DIF	–10 °F DIF
January	$11,428	$11,435 (0%)	$11,460 (0%)
February	$8,158	$8,248 (+1%)	$8,391 (+3%)
March	$5,983	$6,247 (+4%)	$6,571 (+10%)
April	$2,868	$3,294 (+15%)	$3,785 (+32%)

Assumptions:

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70 day 60 night | 65 day 65 night | 60 day 70 night

MICHIGAN STATE UNIVERSITY

Greenhouse Energy Website

www.hrt.msu.edu/energy/Notebook.htm

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