Lowering greenhouse temperatures will reduce heating costs but will likely increase production times. Here we weigh the pros and cons of lowering greenhouse temperatures and provide an idea of what impact cooler temperatures will have on crop quality, timing, and or pest control

The Pros and Cons of Growing Plants Cooler

Ryan M. Warner, John E. Erwin, Michael J. McDonough and Neil Mattson
Department of Horticultural Science, University of Minnesota

It is estimated that approximately 80% of the cost of heating a greenhouse is incurred at night. Given the long nights of winter, heating costs are clearly a major cost in plant production in the north. The dramatic increase in fuel prices last winter caught many people 'off-guard' and reduced profits for many greenhouse growers. The forecast for fuel costs this winter and beyond is uncertain, but it is likely that the higher fuel prices will be with us for some time. The 'bottom line' is that many growers are deciding whether to lower greenhouse temperatures. Lowering greenhouse temperatures will reduce heating costs but will likely increase production times. This article will weigh the pros and cons of lowering greenhouse temperatures and provide an idea of what impact cooler temperatures will have on crop quality, timing, and or pest control. Specifically, we will discuss how temperature impacts seed germination, plant development rate, plant quality characteristics such as flowering and branching, insect and diseases incidences and control and whether the increased production times under cooler temperatures will minimize the savings growers are hoping to realize by reducing greenhouse temperatures. We will also discuss ways to physically save on heating costs.

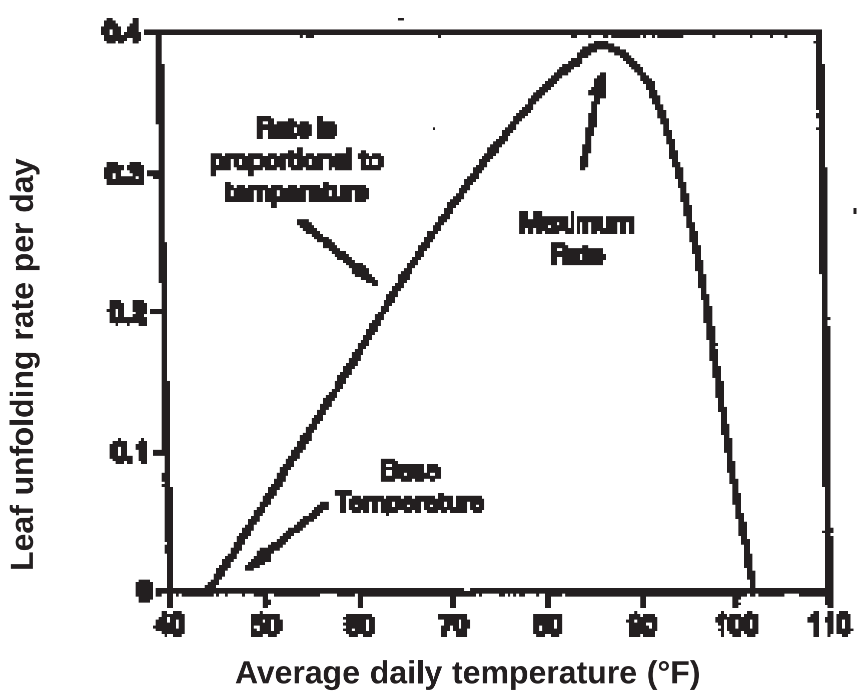
Impact on Plants

Seed Germination

It is critical to provide appropriate temperatures during seed germination!

Continued on next page

Figure 1. Leaf unfolding rate in response to temperature (Erwin, 1995).



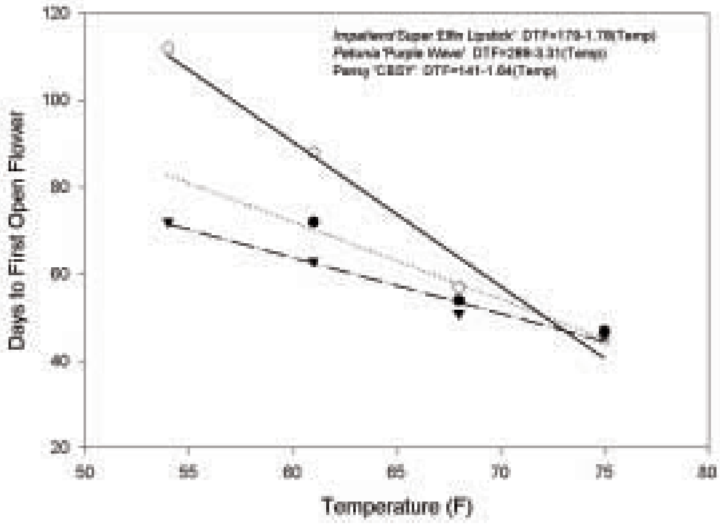
Seed germination and early seedling establishment is one of the most temperature-sensitive stages of plant development. Temperatures too warm or cool during seed germination will delay germination, reduce the percent germination and decrease the uniformity in germination time. Also, cool temperatures (<70 ºF) can promote ‘damping off’ diseases, such as *Pythium* spp.

For most species, germination media temperature should be maintained between 72 and 76 ºF. When your crop is established and actively growing, most species are much more tolerant of cool temperatures than at the seed germination stage. It is important to remember that 1) the temperature on the floor can be 10 to 20 ºF cooler than at bench level and 2) on clear nights plant temperature is lower than air temperature. Never place seed trays on the floor! For these reasons, <u>do not try to save money by dropping temperatures during this stage!</u>

Plant development rate

Plant development rate (i.e. leaf unfolding rate) is dependent on the average daily temperature at which plants are grown. Leaf unfolding rate increases as average daily temperature increases (Fig. 1). Above a ‘maximum’ temperature, leaf unfolding rate declines. Therefore, plants will come into flower earlier when grown under a warmer temperature regime compared to a cooler temperature regime to a point. However,

Figure 2. Impact of temperature on days to flower of three bedding plant species (Mattson and Erwin, unpublished data).



growing plants ‘too hot’ will increase production time!

We conducted research at the University of Minnesota on the effects of temperature on time to flower of a few major bedding plant crops (Table 1). The impact of reducing temperature on days to flower differed across species (Fig. 2). That is, growing plants cooler will increase production time of some crops more than others. For instance,

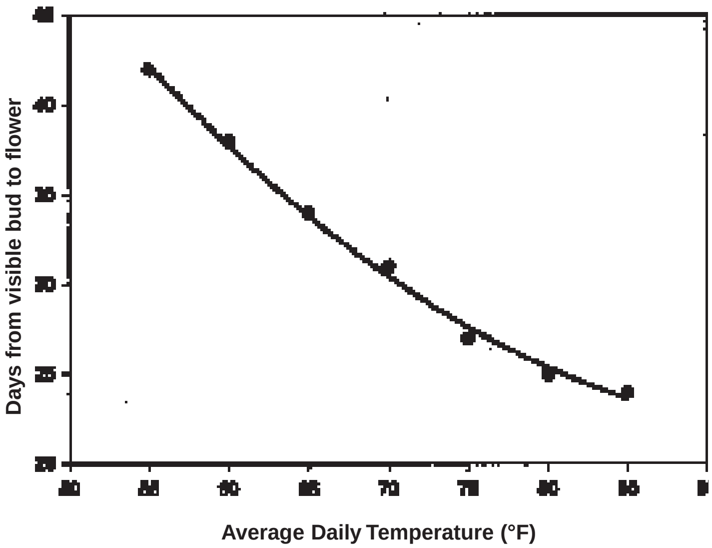
Continued on next page

Table 1. Effect of temperature on the number of days to flower for *Impatiens wallerana* Hook f., Petunia x hybrida Hort., and Gams. (pansy) cultivars. Plants were grown in the reported temperatures from when the cotyledons expanded to when the first flower opened (Mattson and Erwin, unpublished data).

Cultivar	54° F	61° F	68° F	75° F	Delay in Flowering if 24-h Temperature is Reduced 1 ºF (days)*
I. wallerana ‘Super Elfin Lipstick	-	72	54	47	1.8
P. x hybrida ‘Avalanche Pink’	88	74	47	39	2.5
P. x hybrida ‘Dreams Rose’	84	67	46	37	2.3
P. x hybrida ‘Purple Wave’	112	88	57	45	3.3
V. x wittrockiana ‘Colossus Yellow Blotch’	95	82	63	58	1.9
V. x wittrockiana ‘Crystal Bowl Supreme Yellow’	72	63	51	46	1.3
V. x wittrockiana ‘Delta Pure White’	88	71	61	53	1.6
V. x wittrockiana ‘Sorbet Blackberry Cream’	68	60	50	45	1.1

* for temperatures between 54 and 75 ºF
- plants died in this treatment

Figure 3. Easter lily 'Nellie White' reduction in time from visible bud to flower opening under increasing temperature (Erwin and Heins, 1995).



decreasing temperature from 68 ºF to 61 ºF increased days to flower for *Impatiens* 'Super Elfin Lipstick' from 54 days to 72 days, an increase of 18 days. In contrast, decreasing temperature from 68 ºF to 61 ºF increased days to flower for *Petunia* 'Purple Wave' from 57 to 88 days, an increase of 33 days! Most of you are probably considering lowering your greenhouse temperature less than the 7 ºF of this experiment. Still, each 1 ºF decrease in temperature will delay 'Purple Wave' flowering by approximately 3 days (Table 1). Would it be cheaper to keep your temperature higher and decrease your production time, or lower the temperature and increase production time? This, in part, is dependent on the operating cost of your facility.

Temperature also impacts rate of development from visible bud to flower opening. For example, as temperature increases from 55 ºF to 75ºF, days from visible bud to flower opening of Easter lily decreases from 42 to 27 days (Fig. 3). A general 'rule of thumb' is that there is little benefit in increasing average daily temperature above 72 ºF with any crop.

Disease pressure

One very important consideration when producing plants under cool temperatures is the potential for increased disease pressure. This is the result of three things: 1) some diseases are more active at cool temperatures, 2) plants, benches and floors stay wet longer after each watering when temperatures are lower, providing a larger window for pathogen spores to germinate, and 3) plant health of some species is weakened.

Diseases caused by *Pythium, Rhizoctonia* and *Thielaviopsis* are promoted under cool temperatures. For instance, 'damping off' caused by *Pythium* is most severe at 53-68 ºF (Nameth, 2001). 'Damping off' diseases are not the only diseases promoted by cool temperatures. *Thielaviopsis* is the pathogen that causes 'black root rot' and, unfortunately, is becoming a more common problem for pre-finished plants, particularly pansies, vinca and petunias. *Thielaviopsis* can be a problem under either cool or warm temperatures, but *Thielaviopsis* activity is reported to be optimal at 62 ºF (Nameth, 2001). Another widespread disease promoted by cool temperatures is gray mold, caused by *Botrytis. Botrytis* is a problem for pre-finished plants and favored by cool temperatures. Previous research has identified that 71ºF is optimal for *Botrytis* growth and 59 ºF is optimal for *Botrytis* spore production (Nameth, 2001).

When plants are grown cool, they typically require less water than when they are grown warmer. Therefore, each time you water, the media will stay wet longer, and any standing water will take longer to evaporate. Combined, these two factors can increase the root rot disease pressure plants are under. Many diseases require standing water for spores to germinate. Keeping greenhouses cool will increase the opportunities for diseases to become established. It is very important to actively scout for diseases and have a plan for applying fungicides ready before the need arises.

Here are some suggestions for reducing disease severity when growing under cool temperatures (Nameth, 2001):

1) Don't place seed flats/seedlings on the floor! – floor temperature can be 10 to 20 ºF cooler than the air temperature a few feet off the ground; also, having flats on the floor increases the amount of time that free standing water is present, creating germination opportunities for fungal spores. Raising flats off of the floor even a few inches will raise temperature and reduce direct contact with standing water.
2) Keep floors and benches as dry as possible.
3) Keep air circulating - keeping air moving at all levels, not just at bench level, of the greenhouse will reduce the length of time you have standing water after each watering.
4) Use active bottom heating if possible - heating of seed trays to the appropriate temperature will reduce disease severity by promoting actively growing plants, and by raising the temperature above the optimum for 'damping off' disease growth. If you do not already have heating pads, etc. they are expensive to install. However, you may want to consider installing them as a long-term strategy to reduce heating costs.

Keep in mind that chemical activity is reduced at lower temperature. Therefore, it may take longer to see results of an insecticide/fungicide application. It is important that you don't increase the amount of chemical applied.

Insect control

Temperature is the greatest factor determining the development rate of insects. Cool temperatures slow the life cycle of insects (Table 2). For example, decreasing temperature from 80 ºF to 55 ºF increases fungus gnat life cycle time (from egg to adult) from 12 to 27 days (Lindquist, 1998). Similarly, decreasing temperature from 86 ºF to 68 ºF increases western flower thrips life cycle time from 16 to 31 days (Robb, 1989). Therefore, you may need to increase the amount of time in between pesticide applications to maintain the same number of applications during a single life cycle.

Continued on next page

When plants are grown cool, they typically require less water than when they are grown warmer. Therefore, each time you water, the media will stay wet longer. Combined, these two factors can increase the root rot disease pressure plants are under.

Table 2. Impact of temperature on life cycle duration of common greenhouse insect pests.

Insect	Impact of temperature on time from egg to adult	Reference
Aphid – Green Peach*	Increases from 6 to 20 days as temperature decreases from 68 to 50 ºF.	El Din, 1976
Aphid – Cotton/Melon*	Increases from 7 to 10 days as temperature decreases from 77 to 68 ºF	van Steenis and El Khawass, 1975
Fungus Gnats	Increases from 12 to 27 days as temperature decreases from 80 to 55 ºF	Lindquist, 1998
Shore flies	Increases from 10 to 16 days as temperature decreases from 93 to 73 ºF	Lindquist, 1998
Spider Mite – Two Spotted	Variable, but generally increases from 8 to 28 days as temperature decreases from 86 to 59 ºF	Lindquist, 1998
Thrips – Western Flower	Increases from 7 to 13 days as temperature decreases from 98 to 62 ºF	Robb, 1989
Whitefly – Greenhouse	Approximately 21 to 26 days at 81 ºF and 32 to 39 days at 65-75 ºF.	Lindquist, 1998 & Sanderson, 1998
Whitefly – Silverleaf	Increases from 16 to 31 days as temperature decreases from 86 to 68 ºF	Lindquist, 1998

**Aphids do not reproduce by eggs. Reported times are from birth to adult.*

Figure 4. Effect of day and night temperature on flower diameter of Dendranthema x grandiflora 'Bright Golden Anne' (12 ºC=54ºF, 16 ºC=61 ºF, 20 ºC=68 ºF, 24 ºC=75 ºF).

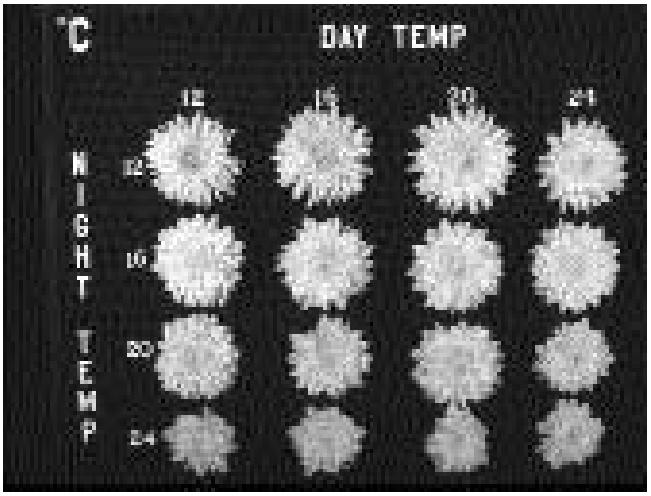
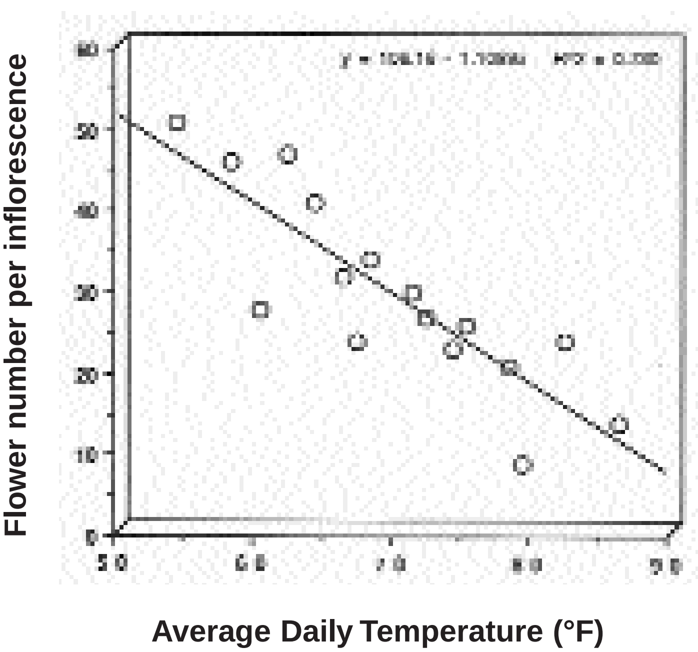


Figure 5. Impact of temperature on number of flowers per inflorescence of zonal geranium 'Veronica' (Erwin and Heins, 1992).



Flowering

One positive impact of reducing greenhouse temperature is that flower size and flower number often increase as greenhouse temperatures decrease. For example, decreasing temperature from 76 ºF to 59 ºF increases flower diameter of chrysanthemum 'Bright Golden Anne (Fig. 4). Flower number per inflorescence of zonal geranium 'Veronica' increases from approximately 15 to 50 flowers as temperature increases from 85 to 54 ºF (Fig. 5). Similarly, decreasing temperature from 77 ºF to 59 ºF increased *Fuchsia* 'Dollar Princess' flower number per inflorescence from 3 to 6 flowers, and increased flower width from 46 to 77 mm.

Branching

Another potential positive aspect of reducing greenhouse temperature is increased plant quality due to increased branching. For example, in *Fuchsia* 'Dollar Princess' single stem pinched cuttings, decreasing greenhouse temperature from 72 ºF to 55 ºF increased lateral branch number at flowering from 6 to 12 branches (Fig. 6).

Dry weight

Decreasing night temperature while maintaining the same day temperature increases plant dry weight,

Figure 6. Impact of temperature on number of later branches at flowering for Fuchsia 'Dollar Princess' (Erwin et al, 1991).

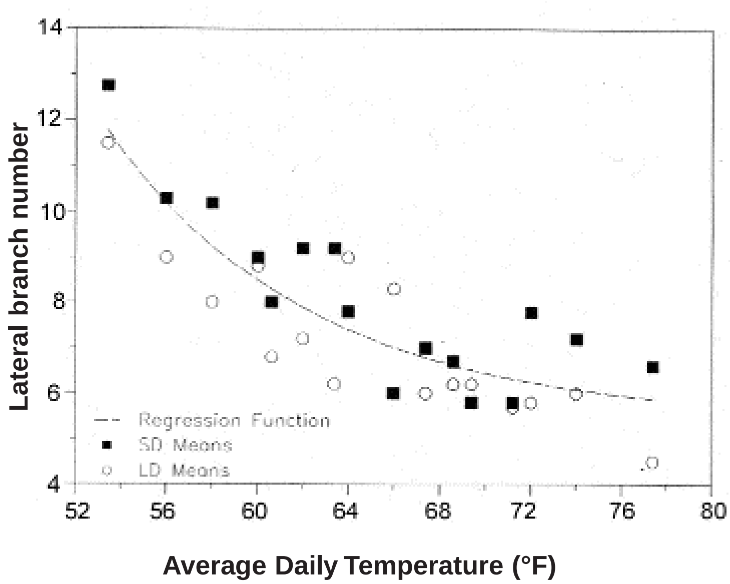


Table 3. Effect of day and night temperature on stem, leaf, flower and total shoot dry weight of 'Mimas' New Guinea impatiens (Erwin, 1995). Data on the percent of total shoot dry weight are presented in parentheses. Plants were grown under a 9-hour photoperiod. Data were collected after 51 days in temperature treatments.

Night Temp. (ºF)	DAY TEMPERATURE (ºF) 59	68	77	86
		Total shoot dry weight (g)		
59	2.8	6.3	7.1	6.7
68	4.6	6.3	6.7	6.8
77	4.7	5.9	6.3	6.8
86	2.3	4.8	4.7	4.2
		Stem dry weight (g)		
59	0.06 (2%)	1.02 (16%)	1.28 (18%)	1.43 (21%)
68	0.07 (1%)	0.86 (14%)	1.14 (17%)	1.42 (21%)
77	0.07 (1%)	0.83 (14%)	1.08 (17%)	1.30 (19%)
86	0.04 (2%)	0.72 (15%)	0.82 (17%)	0.83 (20%)
		Leaf dry weight (g)		
59	2.69 (95%)	3.87 (62%)	4.46 (63%)	4.41 (66%)
68	2.88 (63%)	3.28 (52%)	4.29 (64%)	4.49 (66%)
77	3.30 (71%)	3.71 (63%)	4.16 (66%)	4.95 (72%)
86	2.26 (97%)	3.67 (77%)	3.71 (79%)	3.37 (79%)
		Flower dry weight (g)		
59	0.08 (3%)	1.38 (22%)	1.34 (19%)	0.87 (13%)
68	1.60 (35%)	2.12 (34%)	1.29 (19%)	0.87 (15%)
77	1.30 (28%)	1.33 (23%)	1.05 (17%)	0.59 (9%)
86	0.03 (1%)	0.38 (8%)	0.18 (4%)	0.04 (1%)

The difference between day and night temperatures is known to impact stem elongation

an attribute of plant quality. For example, for New Guinea impatiens 'Mimas' grown at a day temperature of 77 ºF, decreasing night temperature from 77 ºF to 59 ºF increased total stem dry weight from 6.3 g to 7.1 g, a 13% increase (Table 3). However, changing temperatures may affect how a plant uses that dry weight. For instance, dropping temperature from 77 ºF to 59 ºF almost eliminated flowering on New Guinea impatiens.

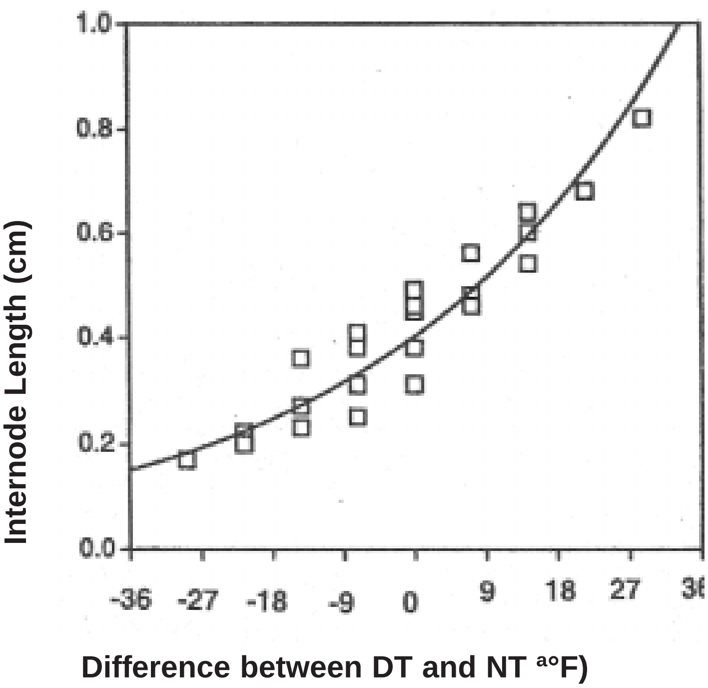
Plants often have an optimal temperature for flowering. Flower dry weight of New Guinea impatiens 'Mimas' was greatest when plants were grown at constant 68 ºF. If either day or night temperature deviated from 68 ºF, floral dry weight decreased (Table 3).

Plant height

As mentioned previously, it is estimated that 80% of the cost of heating a greenhouse is incurred at night. Therefore, if you are planning on reducing temperature, it is likely that you will focus on reducing night temperature. The difference between day and night temperatures is known to impact stem elongation. The greater the difference ('DIF') between day and

Continued on next page

Figure 7. Internode length of Easter lily 'Nellie White' increases as the difference between day temperature (DT) and night temperature (NT) increases (Erwin and Warner, 1999).



night temperatures, the more stem elongation or 'stretch' you will see on your crop (Fig. 7). Therefore, if you are reducing your night temperature only, expect increases in stem elongation. As a result, your crops may require more growth regulator applications, or application at higher concentrations. Alternatively, using a morning temperature dip can help to reduce the necessity for growth regulators. Plants are stretching the most at the end of the night and early in the morning. Reducing temperature 30-60 minutes before dawn and maintaining a lower temperature for the first few hours of the day will reduce the amount of plant growth regulators needed on a crop. This practice is called a morning temperature 'DIP' or 'DROP'. For more information on 'DIF' and 'DIP', see the May 2001 issue of the OFA Bulletin.

Will you really save any money?

Keep in mind that, depending on how much you reduce greenhouse temperature, you may be decreasing the total number of crops you can turn through your greenhouse. If you are strictly a spring bedding plant grower, or you are dependent on producing a certain number of crops (or turns) each season, decreasing greenhouse temperature may not ultimately save you any money. As discussed previously, reducing greenhouse temperature will increase crop production time by slowing the rate of development. Therefore, it is important to compare the total fuel cost of producing a crop under the temperature you would traditionally use with the lower per day costs, but increased production time, of a cooler temperature regime.

Let's use 'Purple Wave' petunia as an example to illustrate how reducing temperature will impact overall fuel usage during the entire production time of a crop. From the equation in Fig. 2 we can predict that 'Purple 'Wave' will flower in 64 days at 68 ºF. For this example, let's assume that you want to reduce your temperature from constant 68 ºF to a regime of 68 ºF day temperature and 58 ºF night temperature (because, as mentioned previously, 80% of heating costs are incurred at night). Therefore, your average daily temperature is 63 ºF. Again from the equation in Fig. 2 we can predict that 'Purple Wave' petunias will flower in 80 days at 63 ºF.

Using information from the Natural Resource, Agriculture, and Engineering Service (NRAES) bulletin *Greenhouse Engineering* (Aldrich and Bartok, 1994), we can compare the approximate total fuel usage for growing 'Purple Wave' under a day/night temperature regime of 68/68 ºF or 68/58 ºF. In Minneapolis, MN we need to provide 19.2 heating degree days (HDD; in this case defined as a 24-hour period in which the inside temperature is 1 ºF higher than the outside temperature) during the night to maintain a 68 ºF night temperature and 16.3 HDD to maintain a night temperature of 58 ºF. Therefore, the approximate number of HDD provided at night to grow 'Purple Wave' at constant 68 ºF is:

19.2 HDD/day *64 days = 1229 total HDD

In contrast, growing plants at 68 F/58 ºF would require approximately:

16.3 HDD/day * 80 days = 1304 total HDD

Therefore, the total amount of fuel required to produce a 'Purple Wave' crop under the cooler temperature regime is approximately 6% **higher** than growing that crop under warmer temperatures and crop time is increased by 16 days. Keep in mind that this is an extreme example. The delay in flowering for growing plants under an average daily temperature of 68 ºF compared to 61 ºF for other crops presented in Table 1 is as little as 9 days for some pansy cultivars, and 22 to 27 days for other Petunia cultivars examined. However, it is important to consider that increasing crop production time under a cool temperature regime may eliminate any fuel savings you gain by reducing the greenhouse temperature in the first place.

Which crops should not be grown cool?

Not all bedding plant crops will adapt well to a cool temperature regime after germination and early seedling growth. The most obvious example is vinca. Celosia, Cleome, Cosmos, Gomphrena, Portulaca and sunflowers are other crops that are adversely affected by cool greenhouse conditions. To deal with this problem, there are two main options: 1) don't grow these crops or 2) group these crops together and maintain a subsection of your greenhouse warmer than the rest of the greenhouse or use heat mats or skirted benches with under-bench heaters.

Crops that grow well under cool conditions

Several bedding plant crops will perform very well under cool temperatures, including snapdragons, alyssum, *Dianthus* and pansy. For these crops, crop quality will not be compromised under cool conditions but crop production time will still be longer than under warmer conditions.

How to Physically Save on Heating Costs

Impact of greenhouse glazing material on heat loss

Different greenhouse glazing materials lose heat at different rates. Single layer glass and single layer plastic film lose heat at the highest rates (approximately 1.1 Btu/hr·ºF·ft2; Aldrich and Bartok, 1994). In comparison, double layer polycarbonate or acrylic loses heat at less than half of the rate (0.5 Btu/hr·ºF·ft^2) of single layer glass or plastic.

Installing a thermal energy blanket can greatly reduce fuel usage for two reasons. First, adding the energy blanket reduces that rate of heat loss from the greenhouse. For example, adding a thermal energy blanket to a greenhouse covered with single layer glass reduces the heat loss rate from 1.1 Btu/hr·ºF·ft^2 to 0.5 Btu/hr·ºF·ft^2 (Aldrich and Bartok, 1994), the same rate as for double layer acrylic. Second, energy blankets reduce fuel costs by reducing the volume of air that you are heating. Why spend money to heat the roof of your greenhouse when your plants are 10 to 20 feet below? The short-term cost of installing

Continued on next page

Reduce your energy bill, both short and long-term

- Install energy curtains
- Reduce air leakage
- Provide heat only where it is needed, i.e. under benches
- Circulate air to reduce/eliminate cold spots
- Install energy efficient heating system
- Calibrate temperature sensors
- Insulate greenhouse perimeter
- Use a double layer glazing material
- Install windbreaks
- Use the cheapest fuel available
- Explore alternative fuel sources

The current 'energy crisis' is not likely to go away any time soon. Therefore, optimizing greenhouse heating efficiency should be a priority for any greenhouse expansion plans.

energy blankets can quickly be recovered by reduced fuel costs.

Here are some tips for reducing your energy bill in both the short- and long-term (adapted from Both, 2001):

- Install energy curtains
- Reduce air leakage
- Provide heat only where it is needed, i.e. under benches
- Circulate air to reduce/eliminate cold spots
- Install energy efficient heating system
- Calibrate temperature sensors
- Insulate greenhouse perimeter
- Use a double layer glazing material
- Install windbreaks
- Use the cheapest fuel available
- Explore alternative fuel sources

The current 'energy crisis' is not likely to go away any time soon. Therefore, optimizing greenhouse heating efficiency should be a priority for any greenhouse expansion plans. You have less flexibility in altering your current structures to increase energy efficiency, but some of the tips listed above can be employed in any greenhouse situation. It is often said that growing plants is as much an art as it is a science. This will certainly be very true as growers search for creative ways to reduce energy costs without sacrificing plant quality and, ultimately, profitability.

References

Aldrich, R.A. and J.W. Bartok, Jr. 1994. Greenhouse engineering. NRAES-33. Natural Resources, Agriculture, and Engineering Service. Cooperative Extension, Ithaca, NY

Both, A.J. 2001. Ten ways to reduce your: energy bill. Greenhouse Grower 19(8):56-62.

El Din, N.S. 1976. Effects of temperature on the aphid, Myzus persicae (Sulz.), with a special reference to critically low and high temperature. Z. Angew. Entomol. 80:7-14.

Erwin, J. 1995. Light and temperature. pp.41-54. In: W. Banner and M. Klopmeyer (eds.). New Guinea impatiens – a Ball guide. Ball Publishing, Batavia, Ill.

Erwin, J.E., R.D. Heins and R. Moe. 1991. Temperature and photoperiod effects on Fuchsia xhybrida morphology. J. Amer. Soc. Hortic. Sci. 116:955-960.

Erwin, J.E. and R.D. Heins. 1992. Environmental effects on geranium development. Minn. Commercial Flow. Growers Bull. 41(1):1-9.

Erwin, J. and R. Heins. 1995. Easter lily production. Minn. Commercial Flow. Growers Bull. 44(5):1-11.

Erwin, J.E. and R.M. Warner. 1999. Temperature p. 69-82. In: Buck, C.A. et al.(eds.). Tips on growing bedding plants 4th ed. O.F.A. Services, Inc., Columbus, Ohio.

Lindquist, R.K. 1998. Identification of insects and related pests of horticultural plants. O.F.A. Services, Inc., Columbus, Ohio

Nameth, S.G.P. 2001. Cool runnings. Greenhouse Grower 19(12):56-64.

Robb, K.L. 1989. Analysis of Frankliniella occidentalis (Pergrande) as a pest of floriculture crops in California greenhouses. Ph.D. Dissertation, Univ. of California, Riverside, Riverside, Calif., 135 pp.

Sanderson, J.P. 1998. Weapons against whitefly. Volume 62. Ball Publishing, Batavia, Ill.

van Steenis, M.J. and K.A.M.H. El Khawass. 1975. Life history of Aphis gossypii on cucumber: influence of temperature, host plant and parasitism. Entomologia Exp. Et Applicata 76:121-131.