

IMPROVING THE COLD CHAIN FOR CUT FLOWERS AND POTTED PLANTS

WHITE PAPER III

prepared by

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Executive Summary

Flowers and plants are shipped through various marketing channels at temperatures that are often too high, resulting in increased shrinkage, disappointed customers, and decreased profits for all segments of the floral industry. To address and this situation and provide suggestions for improvements, drafts of this White Paper were discussed at two PRO Institutes held in Volcano, California by representatives of 47 floral companies and organizations in attendance. The revised draft was then distributed throughout the floral industry with the ensuing feedback utilized to produce the document, White Paper II. Only contact and URL updates are in White Paper III.

Key recommendations that resulted from these discussions

- Cut flowers and potted plants (except for tropical species) should be cooled rapidly to proper temperatures (normally 33-35 F) and maintained at appropriate temperatures (no higher than 41 F) throughout the cold chain. See Addendum A.
- Purchasers (mainly large wholesalers and mass marketers) must drive improvements in flower and plant temperature management during distribution (demand-pull).
- Time/temperature indicators that have been proven effective for floral crops or data loggers should be required in all shipments to document cold chain issues
- Day-ahead flower and plant ordering by purchasers and/or day-ahead flower and plant harvesting by growers is required for many crops to ensure that adequate time is available to cool the products prior to transportation.
- Transportation and/or third party companies should offer precooling services as profit centers to ensure that all boxed flowers and plants placed in trucks are at 32-41F.
- Cut flower heads and potted plant growing media must be probed, temperatures recorded, and results made available to grower, shipper, wholesale, retail, and transportation companies in a timely manner, perhaps by third party inspectors.
- Flowers and plants that are over 41 F should not be transported and must either be cooled to the proper temperature prior to being transported or returned to the shipper.

- The industry should identify and publicize grower, shipper, transportation, wholesale, and retail companies that have adequate low temperature facilities and utilize them properly.
- Proper production procedures need to be implemented to prepare flowers and plants for the rigors of marketing.
- Growers and/or shippers should ensure that flowers and plants are properly treated with appropriate anti-ethylene, anti-yellowing, flower foods, and/or anti-transpirant products to improve product outturn
- The industry must invest in the equipment needed to ensure adequate initial cooling and to prevent breaks in the cold chain.

To achieve the above, the floral industry must

- Inform all industry segments that there is a cold chain crisis.
- Educate all industry segments about the crisis so that they will participate in solving it.
- Encourage all industry segments to take action, especially the purchasers (wholesalers and mass-market retailers).

The Cold Chain Crisis

The US floral industry has changed significantly over the last 100 years. Most cut flowers and potted plants no longer originate in close proximity to consumers. Despite the high perishability of these crops and abundant research-based information emphasizing the importance of proper temperature management in ensuring adequate quality of flowers and plants transported over long distances, the industry fails to ensure proper temperature control during transportation. The combination of long-distance transportation and poor temperature control results in flowers and plants with inadequate longevity being sold to consumers. Consumption trends indicate the results of selling poor quality crops – per capita sales of cut flowers in the U.S. are low and may even be declining.

Improving the consumption of cut flowers will depend on improving the quality of the product in the consumer’s home, and industry leaders are recognizing the importance of addressing transportation issues. It is the goal of this White Paper to address the impacts of temperature, time, ethylene, moisture, disease, and transportation issues on getting cut flowers and potted floral crops to market in satisfactory condition. It is hoped that subsequent discussions of this document will lead to the implementation of specific, achievable, and cost effective measures that will assist the industry in improving cut flower and potted plant consumption.

The problem often starts with the grower/shipper

Domestic and offshore-grown cut flowers often arrive at transportation or consolidation facilities from 10 to 40 degrees F above their ideal holding temperatures. Potted floral crops frequently arrive even warmer. The graph below shows incoming cut flower temperatures recorded for 58 growers at a California consolidation dock over an entire year. Average temperatures for each grower (diamond) were all above 43 F and for some growers were nearly 70 F, with an average of 51 F. In another series of temperature measurements taken at two Florida consolidation docks, incoming cut flower temperatures ranged from 43 to 59 F, with an average of 50 F, while leatherleaf fern averaged 57 F with 19% of the shipments over 70 F.

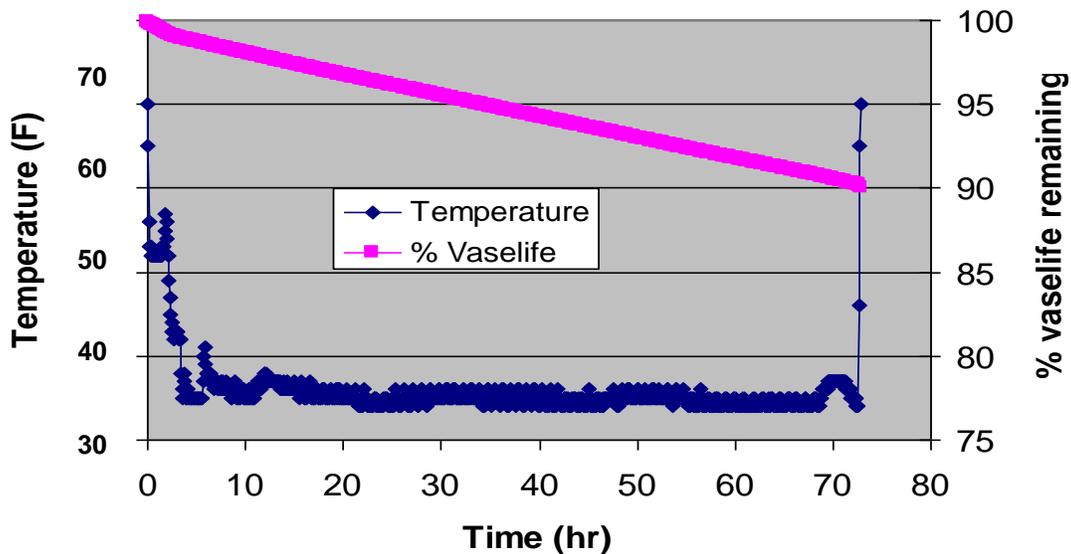
Both time and temperature influence flower and plant quality. Data in the following table shows the effects of temperature on the average respiration rates (heat production) for cut carnations (adapted from Maxie, 1973 and 1974).

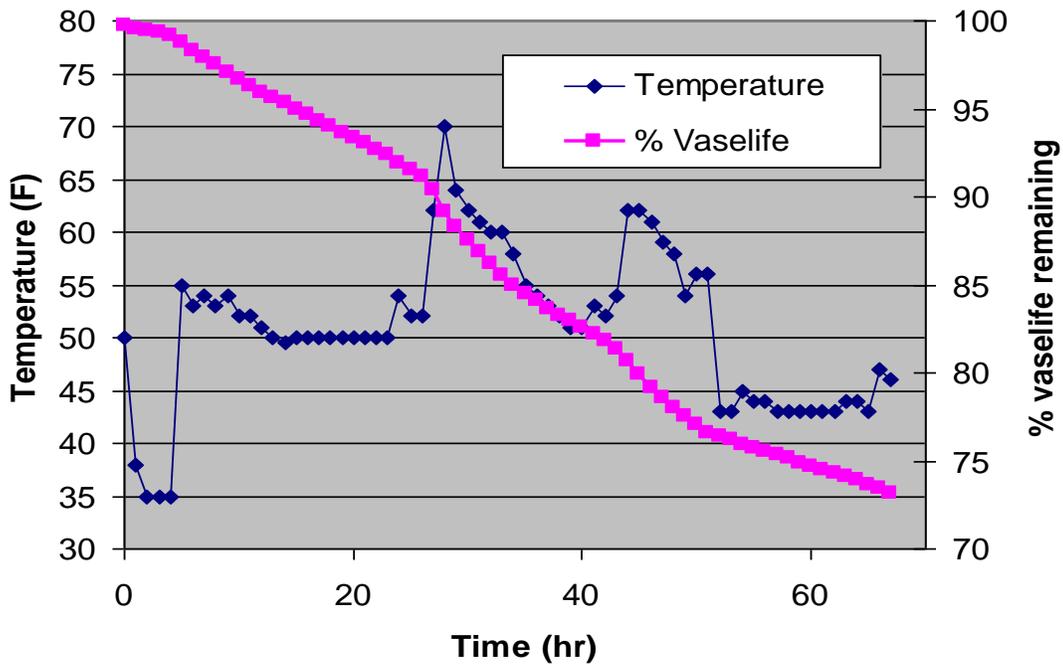
Temperature (degrees F)	Respiration for carnations & roses (mg CO ₂ /kg/hour)	Increase in respiration compared to 32 F (0 C)
32	10	-
50	30	3 times higher
68	266	27 times higher
86	523	52 times higher

At the temperature to which these flowers are commonly exposed (50 F), they respire (and therefore age) about three times faster than at the ideal cold chain temperature (32 F).

Celikel and Reid (2001) also showed that the respiration rates of roses and baby's breath increased by a factor of three when stored at 50 F compared to the proper storage temperature of 32 F. They also showed that there was a strong negative relationship between respiration during storage and subsequent vase life: the higher the respiration, the shorter the vase life. For example, 'Ambiance' roses stored at 32 F for 5 days had a display life of 11.5 days at 68 F, whereas those held at 50 F for 5 days lasted only 7.0 days at 68 F, a 39% decrease in vase life.

Data in the following two graphs depict the variation in temperatures that can be encountered during transportation of cut flowers. The blue/purple lines show the air temperature in flower boxes during transportation for about three days, and the pink lines show how the potential vase life decreases because of poor temperature management. For example, in the first graph, the air temperature in the box is good most of the time but the flowers still lose 10% of their potential vase life. Under poor temperature conditions as represented in the second graph, nearly 30% of the potential vase life is lost during transportation! Unfortunately, data in this second graph is more typical of air temperatures in flower boxes during transit.





Temperature has a dramatic effect on how flowers and plants respond to ethylene levels and ethylene exposure times

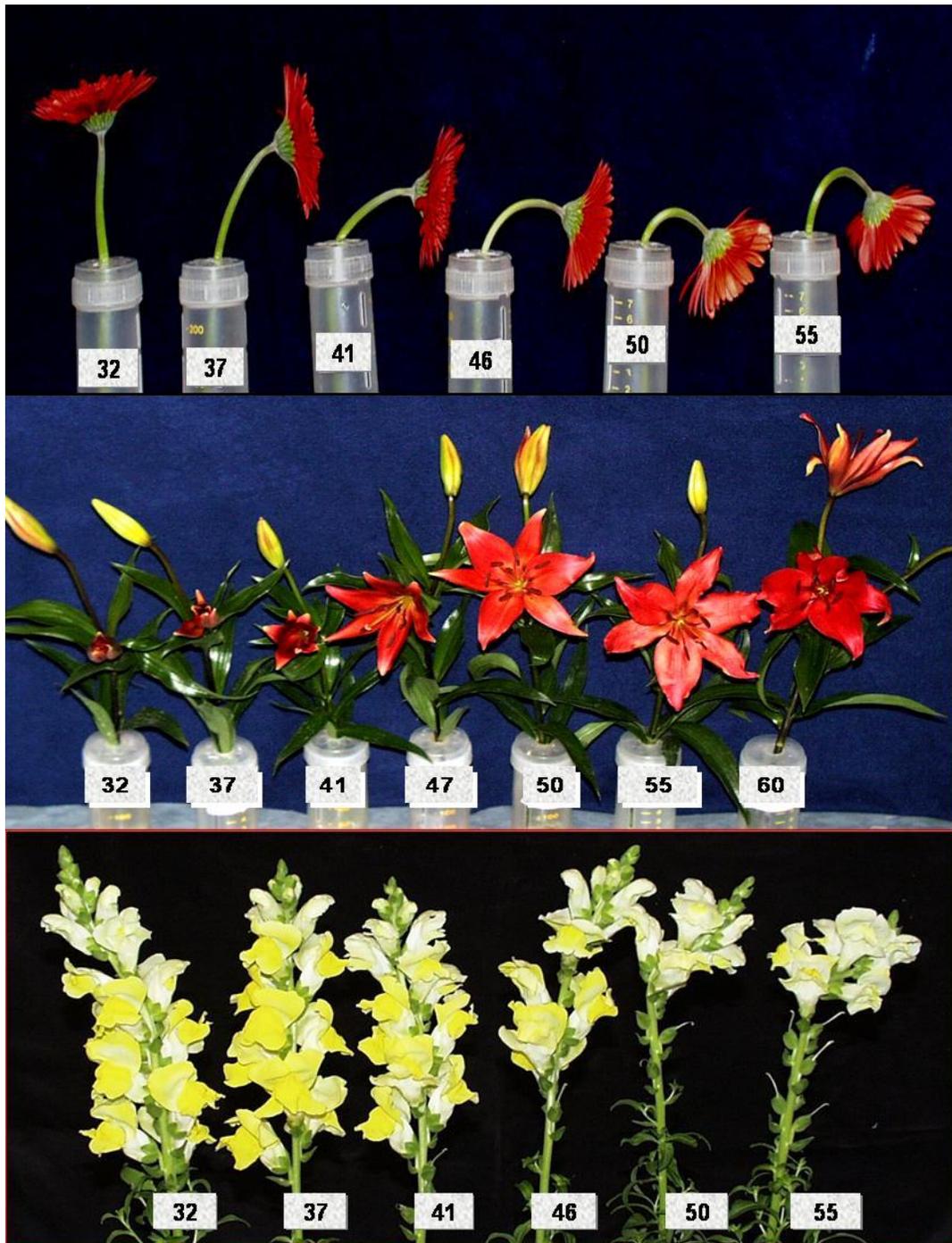
It has long been known that temperature and time have a marked effect on the response of flowers and plants to ethylene. For example, it takes much more ethylene to damage crops at low temperatures compared to when flowers and plants are exposed to ethylene at warm temperatures. A spectacular example of this is shown in the data presented below (MacNish et al. 2004). At room temperature (68 F), waxflowers are very sensitive to ethylene, losing 40% of their blooms when exposed to only 1 part per million (ppm) of ethylene for 12 hours. In contrast, waxflowers treated with the astronomically high ethylene level of 100 ppm for 48 hours exhibited no flower fall when held at 35 F.

----- Exposure time (hours) and flower fall (%)-----

Ethylene (ppm)	Temperature (F)	12 hours	24 hours	36 hours	48 hours
0	35	0	0	0	0
1	35	0	0	0	0
10	35	0	0	0	0
100	35	0	0	0	0
0	68	0	0	0	0
1	68	40	84	72	78
10	68	58	98	100	98
100	68	72	98	100	100

Temperature also affects stem bending, flower opening, petal wilting, and flower fall among other flower and plant characteristics

The following three pictures are worth 3,000 words, as they show the effects of storage temperatures on flower quality. All of the flowers were stored for 5 days at the temperatures noted, then brought out to room temperature (68 F) and held for 1 day (gerberas), 2 days (lilies), or 4 days (snapdragons) in flower food solution before the photographs were taken. Note that seemingly small temperature differences can result in very noticeable flower quality changes.



Inadequate precooling and temperature fluctuations result in condensation, which can lead to *Botrytis* infection

Botrytis, or grey mold, is a very common and destructive fungus found on essentially all flower species. Five factors are needed in order for this disease to thrive: the fungus itself, free moisture and/or high relative humidity, damaged tissue, reasonable temperature, and susceptible hosts. Consider the following research findings:

- It only takes four hours of surface wetness for *Botrytis* spores to germinate and start to grow (Elad, 1989).
- *Botrytis* growth decreases as relative humidity levels decrease from 99 to 94% (Alam et al., 1996).
- Maximum *Botrytis* growth occurs at 68 F but this organism can survive at temperatures as low as 30.5 F (Van den Berg and Lentz, 1968).
- In strawberries, prompt cooling (within one hour of harvest) resulted in a 25% reduction in the incidence of *Botrytis* decay compared with the effect of a six-hour delay before cooling (Nunes et al., 2005).
- Temperature swings during the cold chain can result in sleeves becoming wet due to the formation of condensate, normally on all surfaces. Too warm temperatures increase respiration rates, which again results in moisture formation on sleeves, often more on the inside. The more the moisture, the higher the probability that *Botrytis* will develop.

Clearly, if proper cold chain environments are maintained, problems associated with *Botrytis* infection and growth during this period can be greatly reduced or nearly eliminated.

Solving the Crisis

Proper temperature management pays for itself and then some

Adjusted for inflation from the original research findings (Robertson, 1978), the average net profit increase due solely to proper temperature management at retail level is about 12.2 cents per bunch of flowers in 2005 dollars, which includes the costs of equipment and implementing proper temperature handling techniques. More recently, a major cut flower and greens grower lowered their cooler temperatures from an average of 36-38 F to 33-34 F, and reported reduced shrinkage and claims with an average increase in revenue of 2 to 5 cents per bunch.

The floral industry needs to implement the following to improve the cold chain

1. Cut flowers and potted plants (except for tropical species) must be cooled rapidly to proper temperatures (normally 33-35 F) and maintained at appropriate temperatures (no higher than 41 F) throughout the cold chain. This normally requires using forced air or vacuum precooling technologies. Specific precooling information is presented in Addendum D. However, if day-ahead flower and plant ordering and/or day-ahead flower and plant harvesting is utilized (see number four below), cooling them overnight prior to shipping would allow the crops to be cold at the time of transport.
2. Purchasers (mainly large wholesalers and mass marketers) must drive improvements in flower and plant temperature management during distribution (demand-pull). Only when the companies that pay for the products and transportation services start making

demands will temperature management improve significantly. Thus, start making demands!

3. Time/temperature indicators that have been proven effective for floral crops or data loggers should be required in all shipments to document cold chain issues. There are no excuses for not monitoring temperatures during distribution, especially when some temperature monitoring systems cost pennies per box. Addendum E contains specific procedures that should be followed when measuring flower and/or plant temperatures.
4. Day-ahead flower and plant ordering by purchasers and/or day-ahead flower and plant harvesting by growers is required for many crops to ensure that adequate time is available to cool the products prior to transportation. While almost all floral crops can be harvested and/or ordered in this manner, day-ahead harvesting might work best since growers can sell out of their coolers and buyers have an extra day to order.
5. Transportation and/or third party companies should offer precooling services as profit centers to ensure that all boxed flowers and plants placed in trucks are at 32-41 F.
6. Flowers and plant growing media must be probed, temperatures recorded, and results made available to grower, shipper, wholesale, retail, and transportation companies in a timely manner, perhaps by third-party inspectors, who would provide independent and accurate records. Use durable, needle-type temperature probes.
7. Flowers and plants that are over 41 F should not be transported and must either be cooled to below 41 F (32-35 F preferred) prior to being transported or returned to the shipper. This function would likely work best if third party individuals/companies were involved in making the measurements and subsequent decisions.
8. The industry should identify and publicize grower, shipper, transportation, wholesale, and retail companies that have adequate low temperature facilities and utilize them properly. Highlighting these companies may help to get others to follow suite.
9. The industry must invest in and utilize the equipment needed to prevent breaks in the cold chain. Such equipment includes precoolers, adequate refrigerated storage, sealed and trailer height dock doors, refrigerated docks, refrigerated trucks and marine containers.
10. Proper production procedures need to be implemented to prepare flower and plants for the rigors of marketing. It has been estimated that about 70% of the postharvest quality / longevity / vase life of floral crops is predetermined at harvest. Growers therefore control the bulk of the postharvest quality of floral crops and should become familiar with those production techniques that help ensure good postharvest crop quality.
11. Growers should ensure that flowers and plants are properly treated with appropriate anti-ethylene, anti-yellowing, flower foods, and/or anti-transpirant products to improve product outturn. When used properly, all of these treatments can improve crop quality resulting in higher returns on investments.

Key Summary Questions / Answers / Challenges

How does high temperature abuse reduce flower and plant quality?

- Affects aging
- Affects water loss
- Affects response to ethylene
- Affects *Botrytis* infection and growth

- Affects consumer buying decisions
- Affects profits

How do we institute programs that ensure that consumers receive flowers and plants in the freshest condition?

- Include time/temperature monitors at harvest/packaging and discard or reject product that does not meet strict temperature guidelines
- Cool immediately after harvest, maintain cool throughout the marketing chain.

How do we deal with proper temperature management?

- Forced air for cut flowers and vacuum for potted plants and/or cut flowers
- Refrigerated docks – grower, trucker, receiver, airport, consolidators
- Refrigerated route and long-haul trucks
- Refrigerated aircraft and/or LD-3 type air containers (thermal pallet shippers)
- Refrigerated marine containers
- Independent certification company or companies taking, recording, and reporting data
- Day-ahead flower and plant ordering and/or day-ahead flower and plant harvesting

How do we deal with the biggest problem – product that is too warm at time of shipping?

- Precoolers operated by trucking and/or independent companies
- Charge for the service

How do we deal with offshore product?

- Refrigerated aircraft, refrigerated aircraft pallets, and/or marine containers

How have some companies and organizations reacted to the cold chain crisis?

- Refer to Addendum B to read how some companies initiated policies in accepting flowers based on temperatures.

Where can information and products be obtained to help implement the recommendations presented in this white paper?

- Refer to Product and Service Companies updated in the Chain of Life Network® website at www.chainoflifenet.org verses what is presented in Addendum C.

Editorial Epilogue

The U.S. floral industry has been driven mainly by holidays and special events. Per-capita consumption of cut flowers in the U.S. is low compared to that in many other countries. While supermarkets have become an important outlet for cut flowers and marketing channels have become saturated with inexpensive cut flowers, consumption in the U.S. has stagnated.

One reason for poor floral crop sales in the U.S. is that consumers believe that cut flowers do not last long enough in the home or workplace. We know that poor temperature management after harvest contributes significantly to the short life of cut flowers. Logically, then, improving postharvest temperature management is an opportunity to reverse the trend in per capita consumption by improving customer satisfaction with their purchases. Our White Paper focuses on this opportunity, suggesting tools that will allow sellers and buyers of floral crops to demand and document proper cold chain management. Selling quality product to satisfied customers, we hope that they will lead a resurgence in the U.S. cut flower industry.

Addendum A

Some Background Information

Tropical flowers and cut greens – Cut flowers, greens, foliage and flowering plants that are native to tropical and subtropical regions generally store and ship best at 55-65 F. While it is important to maintain these temperatures, these species are not considered in this document.

Potted floral crops – While most of the information presented in this white paper concerns cut flowers, potted floral crops of the same species have the same postharvest requirements. For example, potted freesias have the same postharvest temperature requirements as cut freesias; both are equally sensitive to ethylene, and both can have *Botrytis*-related problems.

Cold chain and postharvest deterioration nomenclature – As defined in this document, the cold chain starts the moment flowers/plants are harvested and ends when they are purchased (or discarded) at retail level. Cold chain issues are generally only temperature related. On the other hand, postharvest deterioration occurs throughout this same period but is the combined effects of postharvest temperature, relative humidity, time, ethylene levels and disease on subsequent flower/plant freshness and longevity. While cold chain is the more common expression, understanding and controlling postharvest deterioration is what this white paper is all about.

Articles cited in this document – Can be found in the Chain of Life Network® Database in www.chainoflifenet.org by searching for them using author name and year.

Addendum B (as of 2005)

Some Initiated and Future Programs to Help Improve the Cold Chain

[Prime Floral LLC](#) introduced the following policy that addresses the subject of acceptable flower temperatures at the time of tendering the flowers to them:

“When boxes are tendered at a temperature above 50 degrees Fahrenheit the shipping vendor will immediately be notified. The shipping vendor will be given the opportunity to pre-cool the box to an acceptable transportable temperature within the time frame allotted for on-time departures at their own expense. As a result, we may refuse to transport individual boxes of product if the temperature after pre-cooling exceeds 50 degrees Fahrenheit at the time of their scheduled departure.”

A recently initiating wholesaler’s policy in accepting flowers:

“We at [Delaware Valley Floral Group](#) understand the importance of proper cold chain management for the longevity of cut flowers and potted plants. For that reason, we have decided to introduce and implement the Cool-chain policy, in order to improve product quality and assure cool-chain management is implemented successfully. Effective 8th of June 2005 no Delaware Valley Floral Group Divisions will accept any product arriving at California consolidation point/transportation facility above 44° F for Fresh Cut Floral products and, above 60°F for Tropical products. Once the product is checked by the California Quality Assurance Auditor at receipt and it is found not compliant to the temperature policy, the floral product will not be accepted and needs to be taken back by the vendor.”

Delaware Valley has also placed a fulltime employee in California to monitor incoming flower and plant temperatures at the receiving points and to reject those that do not meet the specified requirements. The same policy is in effect for local brokerage vendors in Miami but not in effect for the product arriving directly out of the airlines from South America in Miami. However, they do

measure representative arrival temperatures of all flowers to find out what they are and then pre-cooled them to 37 degrees before transit to New Jersey.

In another example, a group of wholesalers is trying to implement a policy whereby no flower would be accepted at consolidation points that was over 40 F. For those flowers identified as being over 40 F, they would be pre-cooled for a fee that would be paid for by the wholesalers who in turn would deduct these pre-cooling fees from the flower vendor invoices.

Finally, the [Wholesale Florist & Florist Supplier Association](#) has announced the goal of its Logistics Committee: "to identify and promote best practices that take costs out of, and/or add value to, the wholesale distribution channel." Cold chain improvements fit nicely into this goal.

Addendum C (as of 2005, go to Product and Services Companies in the Chain of Life Network® website for an updated list)

Some Information, Equipment Sources, and Associations to Improve the Cold Chain

A wide range of free information and equipment sources to improve the cold chain are available on the Internet at <http://www.chainoflifenet.org>, <http://postharvest.ucdavis.edu/>, and (<http://www.ba.ars.usda.gov/hb66/>).

Specific sources related to the cut flower cold chain subjects presented in this "White Paper" are listed below.

- Air handling system designs for forced air (positive pressure) precoolers:
 - Rainbow Coolers (Mike McKiernan) at 503-897-3304 or mikehmck@aol.com
- Some leasing and/or sales companies in the U.S. for intermodal (marine) containers, which can be used for storage units:
 - Portable Cold Storage 800-535-2445 <http://www.portablecoldstorage.com/>
 - Carlisle Leasing International 925-946-4290 <http://www.carlisleleasing.com>
 - Danicon <http://www.danicon.com>
 - The RCS Group 281-470-1924 <http://www.rcsgroup.com/>
 - Interport Maintenance Company 973-589-2329 <http://www.iport.com/>
 - Portable Container Services 866-472-6256 <http://www.portablecontainerservices.com>
- Some chemical treatments to help improve the postharvest quality of floral crops:
 - Anti-yellowing products include BVB and SVB (<http://www.chrysalusa.com/pokon/>), Fascination (<http://www.valent.com>), Aquafinish Clear (<http://www.syndicatesales.com>) and PAL (<http://www.floralife.com>)
 - Anti-ethylene products include MCP sold as EthylBloc (<http://www.floralife.com>) and STS sold as AVB (<http://www.chrysalusa.com/pokon/>)
 - Anti-stress and/or hydration products include Hydraflor (<http://www.floralife.com>), Hydroseal (<http://www.hydroseal-products.com/>), RVB (<http://www.chrysalusa.com/pokon/>), and Hydraplus (<http://www.syndicatesales.com>)
 - *Botrytis* control products include Phyton 27 (<http://www.phytoncorp.com>), Exotherm Termil (<http://www.fullersystem.com/> or <http://www.valuegardens.com>), and Sportak (<http://www.bayercropscience.com.au/>).

- Improving loading docks for the transfer of crops from coolers to trailers and *vice versa*:
 - <http://www.detroitdoor.us/>
 - <http://www.fairbornusa.com/>.

- Understand the advantages of reducing fertilization and/or irrigation of cut flowers and potted plants prior to harvest and implement these procedures when appropriate:
 - Contact george.staby@volcano.net for specific information in these subject matters.

- Taking flower and/or plant temperatures and recording the readings on bills of lading and/or applicable computer programs:
 - A program developed for the floral industry called e-Faqs (<http://www.e-faqs.com>) or a general program like Microsoft Excel can be utilized for tracking the temperature data taken but does not measure temperatures.
 - Investigate the possible use of <http://www.floralship.com/>, which is a package and inventory tracking system that could also retain temperature information.
 - Investigate the use of Radio Frequency Identification (RFID) labels that also measure and record temperatures from companies such as <http://www.montalbanotechnology.com> and <http://www.infratab.com/>.

- Representatives from the following organizations are encouraged to discuss the subjects described in this White Paper and, when feasible, take appropriate actions.
 - [Association of Floral Importers of Florida](#)
 - [Association of Specialty Cut Flowers](#)
 - [California Association of Flower Growers and Shippers \(NORCAL\)](#)
 - [California Cut Flower Commission](#)
 - [California State Floral Association](#)
 - [Colombian Association of Flower Exporters \(ASOCOLFLORES\)](#)
 - [Connecticut Florists Association](#)
 - [Fresh Produce and Floral Council](#)
 - [International Cut Flower Growers Association](#)
 - [OFA - An Association of Floriculture Professionals](#)
 - [Produce Marketing Association](#)
 - [Society of American Florists](#)
 - [Wholesale Florist & Florist Supplier Association](#)

Addendum D

Precooling Cut Flowers and Greens

In 1979, USDA and university researchers Roger Rij, Jim Thompson, and Delbert Farnham wrote the following in a bulletin describing systems for pre-cooling and storing flowers. *“Under present procedures, the cooling of packed flowers is the weakest link in most handling systems. Producers of field-grown flowers find that they cannot take advantage of field packing because they lack a method of quickly removing field heat. Flower shippers also recognize that flowers shipped by truck do not always arrive in good condition because they reach excessively high temperatures in transit. Temperature problems in transit can be greatly reduced by use of forced-air cooling prior to shipping.”*

Little has changed in the intervening years, apart from the introduction of Proconas and other “wet pack systems”, which present their own pre-cooling challenges. However, recent action by wholesale buyers and trucking companies setting maximum temperatures for cut flowers intended

for long distance transport has resulted in renewed interest in this subject. We provide here a revision and update of the pre-cooling portion of our earlier bulletin.

In most cases, field heat can be removed from bunched flowers in about 20 minutes simply by placing the bunches in a cooler. Packing the flowers in boxes restricts the movement of refrigerated air to the flowers and increases the time taken to remove field heat. It can take 2 to 4 days to cool a stack of packed boxes of warm flowers. A warm load of flowers in a refrigerated truck may never reach the recommended temperature during a 3- to 4- day trip, and may even heat up, due to the high heat of respiration of warm flowers.

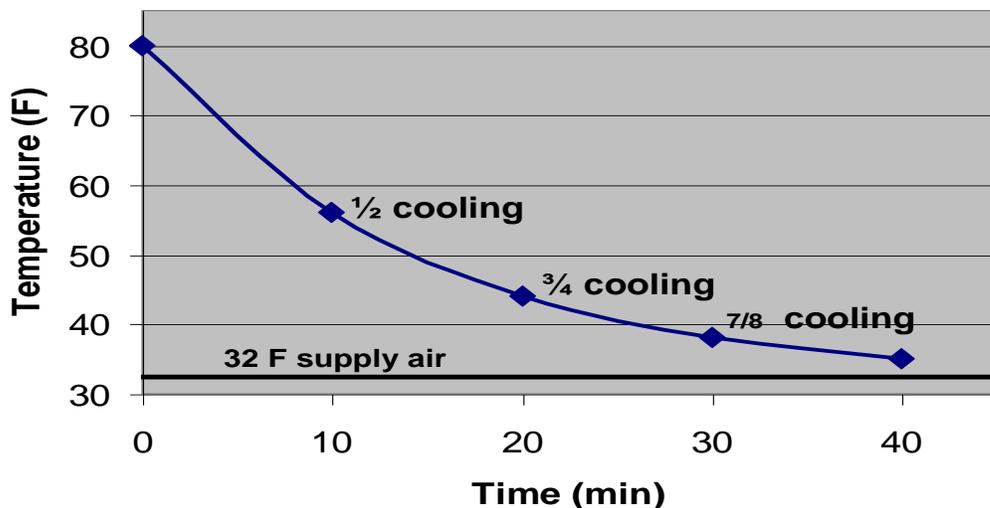
Forced-Air Cooling

Forced-air cooling is a method of moving refrigerated air through a packed box of flowers to reduce their temperature quickly. Most flowers can be cooled to recommended temperatures in 45 min to an hour, and some cut flowers can be cooled in as few as 8 min. For small volumes of packed flowers, this is done by stacking boxes around a fan inside an existing cooler. In larger systems, many fans are permanently mounted against a wall, and pallet or cartloads of boxes are positioned next to the fans. The refrigeration system needs to be carefully designed and sized for forced-air cooling.

Cooling Time Calculations

The time necessary to reach a desired temperature is expressed in terms of a typical cooling curve. The seven-eighths cooling time, or the time required to reduce the temperature of the flowers seven-eighths of the way from the initial temperature to the temperature of the cooling air, is a measurement for commercial coolers. This relationship is exemplified in the following figure. Note that the rate of cooling becomes very slow as the temperature of the flowers nears the temperature of the refrigerated air. Consequently, flowers are seldom completely cooled to the temperature of the cooling air. In the cooling data depicted in this figure, half an hour of cooling is required to reach 37.5 F (seven-eighths cooling). More than 2 hours cooling would be required for the flowers to approach the temperature of the cooling air (32 F).

Cooling curve for cut flowers in a forced air cooler with supply air at 32 F. The half-cooling time for these flowers is 10 minutes



Fans

Forced-air coolers use squirrel cage (centrifugal) or propeller (axial flow) fans. Centrifugal fans are much quieter than axial flow fans and can move more air against higher static pressures, but may require greater horsepower to operate. Fans are selected based on two criteria – the required airflow, measured in cubic feet per minute (cfm), and the required static pressure, measured in inches of water. The specific requirements are determined by the type of flower, the number of boxes, and venting of the boxes, and the rate of cooling desired.

The airflows and pressures needed to cool a full-sized California box of different types of flowers are depicted in the following table. In designing a precooler, the airflow (cfm) required can be estimated by multiplying the required cfm per box by the number of boxes that will be cooled, and adding 25% to allow for air leaks. The number of boxes to be cooled should be based on the maximum number handled on a peak day (such as the period just before a holiday). It is not advisable to use higher airflows than those listed in the table. They will not significantly increase the cooling rate, and will require excessive amounts of energy. The pressure drop for the system is equal to the pressure drop across one box plus 25 percent additional pressure as a safety factor. *Do not attempt to cool boxes stacked end to end.*

Forced-air cooling: static pressures, airflows, and cooling times required to cool standard boxes of specific flowers

----- Static pressure -----

Flower type*	0.5 inch		1.0 inch		2.0 inch	
	Airflow	7/8 cooling time	Airflow	7/8 cooling time	Airflow	7/8 cooling time
	<i>Cfm/box</i>	<i>Minutes</i>	<i>Cfm/box</i>	<i>Minutes</i>	<i>Cfm/box</i>	<i>Minutes</i>
Carnations	70	48	90	40	110	35
Chrysanthemums	80	62	130	58	210	54
Gypsophila	170	10	260	8	--	--
Roses	140	34	200	25	290	20
Statice	150	40	210	18	280	13

*Carnation box size 48x21x12 inches, with two 2-inch diameter vent holes in each end, 51 lb gross weight

*Chrysanthemum box size 57x21x12 inches with two 2-inch diameter vent holes in each end, and 33 lb gross weight; 45-lb box will allow 50% less air through the box.

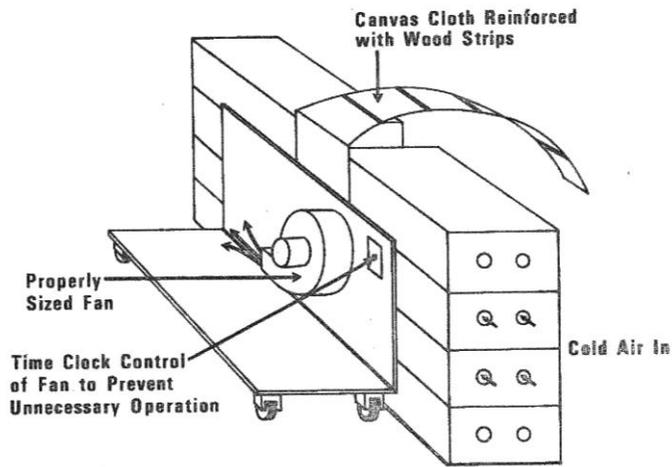
*Gypsophila box size 42x21x12 inches with two 3-inch diameter vent holes in each end

*Rose box size 48x21x12 inches, with two 2-inch diameter vent holes in each end, 20 bunches per box.

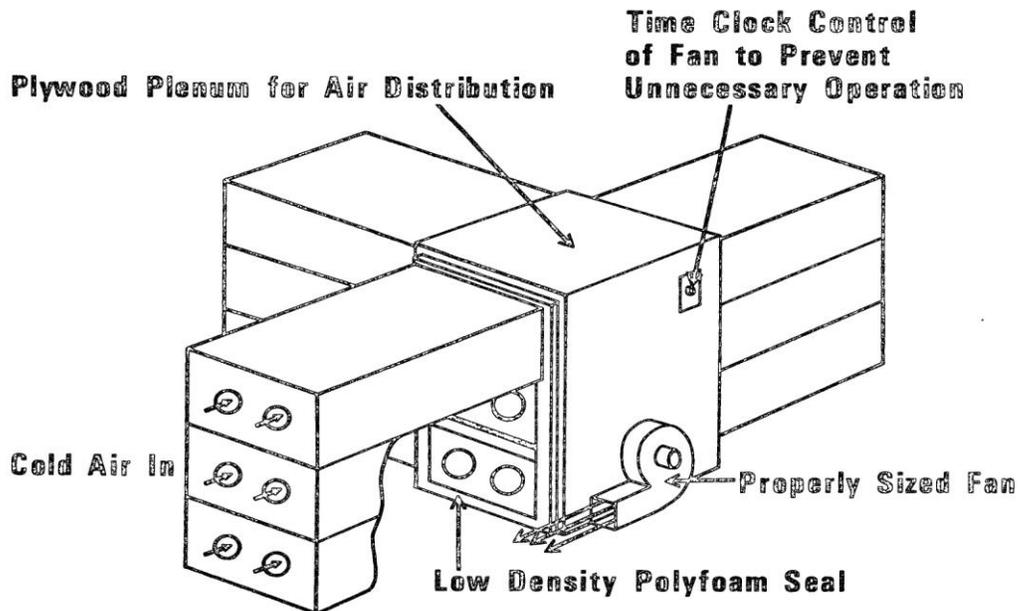
*Statice box size 42x21x12 inches with two 3-inch diameter vent holes in each end and gross weight of 75 lb.

Forced-air cooling systems come in many forms, as depicted in the following five figures.

Simple forced-air precoolers



A different approach to retrofitting a room with a forced air cooler for cut flowers

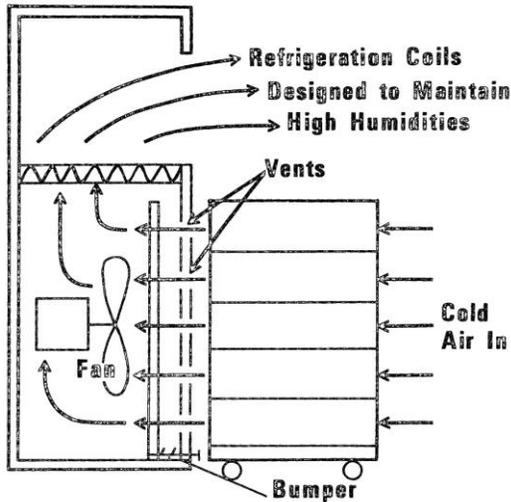


Precooling facilities that handle more than 30 to 40 boxes per hour must be designed specifically for flowers. Boxes are often handled in stacks of six to eight feet high and are set on wheeled dollies or pallets.

Cold wall system:

The dollies or pallets are placed in front of a plenum called a cold wall.

Cold wall forced air-cooling systems



The cold wall may have a set of vents that are opened by the action of pushing the boxes against the wall (diagram), or, more simply, a canvas blind (roller blinds work well) can be pulled down to cover the unused portion of the cold wall (photograph).

Tunnel cooling:

As demonstrated in the following two figures, dollies or pallets are arranged in two columns, separated by several feet, on either side of a fan opening. The space between the columns is covered by a reinforced canvas cloth, causing the air to be pulled through the boxes.

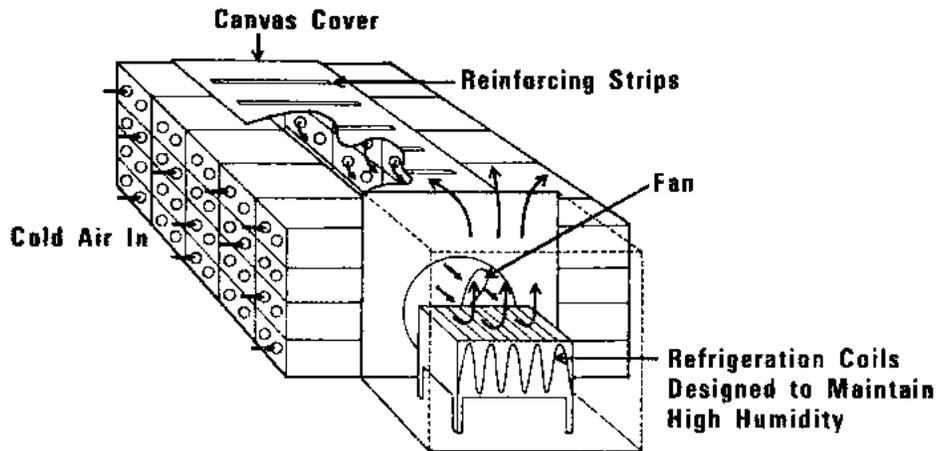
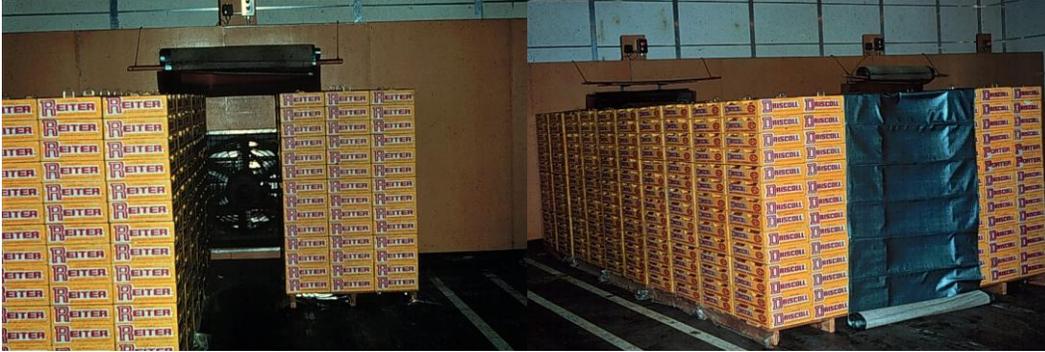


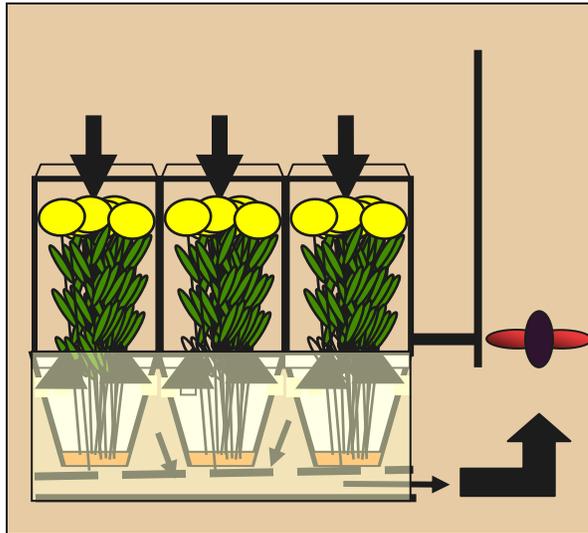
Diagram of a tunnel pre-cooler for cut flowers



A tunnel pre-cooler (for strawberries) showing how the tunnel is assembled (left) and operated (right). For flowers, the base of the pallets have to be sealed (plastic or fiberboards trips, or sand 'snakes') to prevent short-circuits of the precooling air.

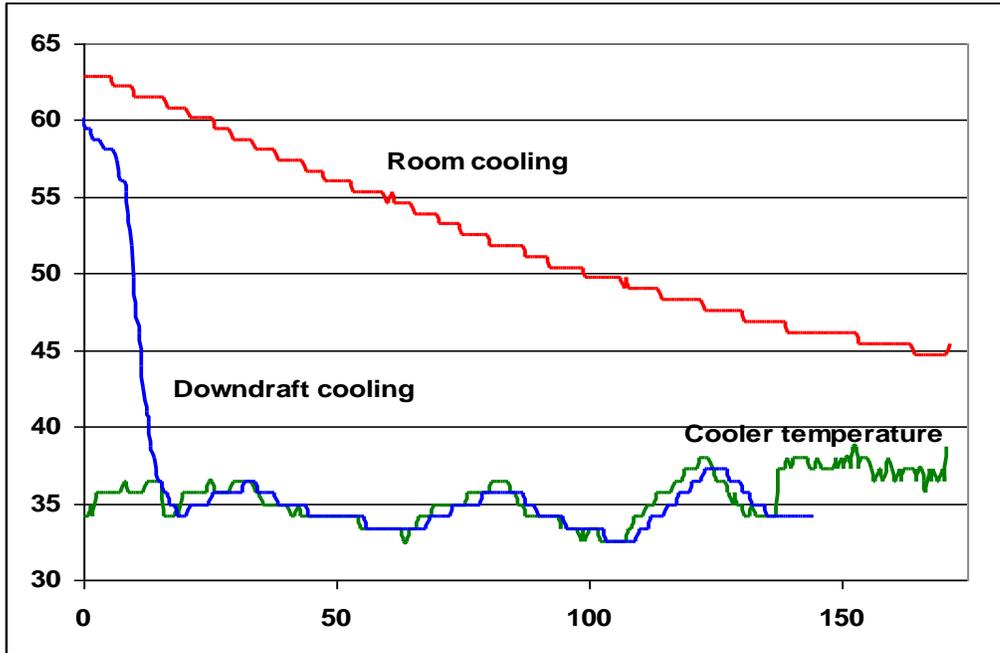
Cooling Proconas:

The sleeves that surround the flowers in water packs such as 'Proconas' prevent precooling using the standard systems described above. With a minor modification, air can be forced to move down through the boxes, and such boxes can then be cooled rapidly (see figure below). Boxes are stacked on a pallet, and the pallet is placed against a plenum that is designed to draw air from the bottom of the boxes and the pallet. A strip of canvas or sheet of fiberboard around the bottom of the boxes and the pallet ensures that air is drawn down through the boxes.



Precooling Procona boxes on a conventional horizontal pre-cooler is achieved by directing the airflow down through the boxes using an adapter plenum, and a fiberboard or fabric sleeve around the base of the boxes.

This Procona precooling system works very efficiently, and flowers are cooled with a half-cooling time of only a few minutes (see below).



'Downdraft' cooling of flowers packed in 'Procona' water packs. Packed flowers were placed either in a cool room or on a downdraft cooler.

Refrigeration:

The refrigeration system must be designed to maintain a temperature equal to the lowest storage temperature of the crops being cooled (often 32 F). The actual refrigeration requirements necessary to cool flowers should be determined by an engineer, but can be estimated as follows:

Maximum number of full-size boxes cooled per hour	Approximate refrigeration Capacity needed (tons)
5	2-3
10	3-4
20	6-8
40	12-16

Many existing refrigeration units can handle the heat load from 5 to 10 boxes per hour. Insufficient refrigeration capacity will cause increased cooling times because it will not maintain consistently low air temperatures. It may also result in low humidity, which will increase desiccation of the flowers.

The relative humidity in the cooler should be about 93%. This high relative humidity can be maintained in several ways. In a small system, periodic hosing down of the walls and floor can help keep the humidity high, although more frequent defrosting of the coils will be required. In systems designed for precooling, high humidity is maintained by the use of a large refrigeration coil surface and a humidifier, or by the use of a wet coil system.

Forced-air cooler operation:

Proper packing of the flowers is vital to effective precooling. All paper that inhibits uniform horizontal movement of air through the box must be eliminated. Paper or plastic placed on the ends of the box will prevent cooling air from reaching the flowers. Flowers should be secured in the box, maintaining a 1- to 2-inch separation between the flower heads and the box ends. This space allows the cooling air to be uniformly distributed in the box.

The time required for individual boxes to be cooled varies significantly. Different flower species cool at different rates. Incorrect placement of paper or sleeves can retard or prevent cooling. The number of boxes on the cooler can affect cooling times. These facts require that the temperature of the flowers be monitored closely during cooling. Boxes should be removed only after the temperature of the flowers inside the box has been checked at both the warm and cool ends of the box. Data sheets, indicating the initial and final temperature of all loads of boxes, should be kept.

The following equation can be used to calculate the time required to cool a box of flowers to a specific temperature:

$$V = 0.903 T / (\log(S - M / F - M))$$

Where:

V = 7/8 cooling time

S = initial temperature of the product (°F)

T = time to cool to temperature F, and

M = temperature of cooling air entering the box

Vacuum cooling

While research documenting the advantages of vacuum precooling floral crops dates back to the 1950s, few such systems have been used commercially. More recently, however, vacuum coolers have been installed in flower marketing terminals (mostly near airports but also by a few growers) as a means of removing heat from packed flowers.

Vacuum cooling is based on the fact that water boils at lower temperatures at lower pressures. At about 1/10th atmosphere pressure, water boils at 32°F. When flowers or plants are placed at these low pressures, the water in their cells 'boils', removing heat. Although these systems cool leaves, stems, and growing media promptly and efficiently, flower petals often cool somewhat more slowly, because water cannot escape readily from them. Essentially the same seven-eighths precooling time (or possibly 10-15 minutes less) is required to vacuum cool flowers as for the forced-air cooling systems.

When used at or near airports, these systems serve as a useful 'backstop' for flowers that have not been properly cooled by growers and/or shippers. However, in some cases it can be many hours before packed flowers arrive at the airport or trucking dock, which suggests that they may have already deteriorated significantly before being placed in a vacuum cooler.

Some advantages of vacuum cooling methods include that paper and plastic packaging materials in the boxes do not affect the efficiency of cooling, free water is removed, boxes can be stacked in any manner in the precooler, and it can work equally well with dry packs and wet packs for cut flowers and greens and for potted plants. The main disadvantage is the high cost of the equipment.

Addendum E

Proper Ways to Measure Flower and/or Plant Temperatures Accurately

Research was conducted at the University of California, Davis in August, 2005 by Jim Thompson, Michael Reid, and George Staby to determine which type of temperature probes work best to measure cut flowers and greens in shipping boxes. Several infrared, standard needle probe, and computer-connected thermometers (as references) were tested. No infrared temperature probe tested worked well enough to be recommended. Only durable and thin needle-like temperature probes attached to battery-operated digital readouts are being recommended at this time. While 1/16 inch diameter probes measure temperatures faster, 1/8 diameter probes are more durable.

As background, infrared thermometers work by aiming the device towards the object to be measured, with the temperature being displayed almost instantly without the device touching the object. While simple to use and some units are available for \$40 or less, the following limitations preclude them from being recommended.

- Only surface temperatures are recorded, which can result in false readings when warm floral crops are being cooled, or cool crops are exposed to warm air;
- If the probe is not aimed properly, false readings are possible;
- For sleeved flowers, greens, and/or potted plants, one can be measuring sleeve temperatures, not flower or foliage temperatures;
- The greater the difference between the temperature of the crops and air temperature where the readings are being taken, the higher the probability of false readings;
- Differences between the temperature of the infrared device itself and the air temperature where the readings are being taken may also result in false readings.

There are also limitations using needle probes.

- Probes that are too thick take longer to equilibrate and thus longer to measure temperatures accurately;
- The bigger the difference between the probe and crop temperatures at the time of probing, the greater the time needed for temperature equilibration and the greater the possible temperature measurement error. This is why it is recommended that the probe be withdrawn and reinserted immediately to reduce this error possibility.

The following describes how to use the needle probe thermometers properly.

Prior to use and at least once per month thereafter, follow the manufacturers' directions to calibrate the probes and check batteries. If calibration directions are not provided, fill a large cup with crushed ice and then add cold water to the brim. Stir the ice water slurry for about one minute with the needle probe. The temperature should read 32F (0C). If needed, adjust to 32F (0C) following the manufacturers' directions. Do not use the thermometer if it is out of calibration by more than 1 degree F and cannot be adjusted to read correctly.

To measure the temperature of cut flowers and greens:

- 1) For big/dense flowers such as roses, carnations, chrysanthemums, and sunflowers, insert the probe directly into a flower head through a precooling vent hole in the box or from the top or handle holes for cut flowers shipped in wet packs.
- 2) If the flower heads are too small to be probed directly or when shipping cut greens and foliage plants, insert the probe six inches into the flower/foliage mass, again through the precooling vent holes or from the top or handle holes for wet packed cut flowers.
- 3) After about ten seconds, pull the probe out and immediately reinsert it in a different flower or area of flowers and foliage.

- 4) Wait until the temperature readout stabilizes, which is determined when it changes less than 0.2 degrees F in about five seconds.
- 5) Record the results.

To measure the temperature of potted plants:

- 1) For big/dense flowers such as chrysanthemums, insert the probe directly into a flower head through the top of the box or handle holes if present and feasible.
- 2) If the flower heads are too small to be probed directly or there are no flowers present like with foliage plants, insert the probe directly into the growing media.
- 3) After about ten seconds, pull the probe out and immediately reinsert it in a different flower or area of the growing media.
- 4) Wait until the temperature readout stabilizes, which is determined when it changes less than 0.2 degrees F in about five seconds.
- 5) Record the results.

There is no reason to take temperature readings if they are not written down, filed, shared with others, and/or acted upon to improve product outturn. Such documentation can be simply recording the results in a logbook, entering them into a computer program like Microsoft Excel, or noting them directly on transportation documents like waybills.

The following are some additional floral crop temperature measurement points to consider.

- When needle probes are inserted directly into flower heads, no perceived flower damage should result if the probe is thin enough such as 1/16 inch in diameter.
- Do not remove box lids from dry packed cut flowers prior to probing the flowers. This is one reason why it is recommended to probe the flowers through the precooling vent holes. If vent holes are not present, use an ice pick or thin screwdriver to make a hole in one end of a box through which the temperature probe can be easily inserted.
- For wet packed cut flowers and/or greens, also measure and record the solution temperature, as the solution temperature should also meet the same temperature specifications as the flowers and greens.
- Most cut flowers and potted plants (except for tropical species) should probe no higher than 41F with the ideal being between 33 and 35F.
- Most tropical species should probe between 55 and 65F.
- Written policies should be in place to delineate what should be done when crop temperatures are measured outside the recommended ranges. For example, non-tropical cut flowers and potted plants that probe higher than 41F should not be transported until their temperatures are lowered appropriately.
- Some sources of acceptable temperature probes, tracking systems, and data collection related programs are listed in Addendum C.

GS/MR/kv