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***project concluded by Tim Briercliffe**

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1. Summary

1.1 Headline

Among other benefits cold storage can be used to delay flowering and growth in a large range of container-grown nursery stock species to better meet customer demand. For this to be viable the store only needs to provide a 10% increase in saleable yield of 3 litre stock and just a 3% increase for liners.

1.2 Background and Objectives

Accurate scheduling is becoming increasingly important in the production of hardy nursery stock in the UK, particularly for those growers who supply garden centres and multiple retailers. These outlets are continuing to demand smaller amounts of product on a more regular basis, and high volumes at specific marketing periods throughout the year. However, these represent narrow windows of opportunity, and adverse weather conditions at these specific times can cause considerable losses through unsold product. The retailer is rarely willing to carry these losses.

An increasing amount of nursery stock is being produced under glass. The use of cold stores to hold stock can increase the throughput of these structures considerably, enabling a higher return per m^2 of glass each year. Labour inputs can be utilised more effectively by removing some of the peaks and troughs of seasonal production. The ability to hold liners enables the development of scheduled potting regimes, which would also increase throughput on the nursery.

Successful restriction of growth would enable season extension through delayed vegetative and reproductive growth. It will be possible to manipulate flowering with low temperatures and to extend periods of marketing in flower or in bud. The technique would allow the grower to hold plants at specific growth stages and thereby improve crop uniformity; and to build up the large volumes of stock required for times of maximum demand.

Possible future developments in the export of nursery stock from the UK will depend on storage techniques to facilitate the process and ensure quality plants at the point of sale.

This project is a review is to assess the feasibility of using low temperatures to suppress growth and development in nursery stock species. Subsequent plant quality is of the utmost importance to growers and it is essential that plants do not suffer any adverse long or short-term effects as a result of using cold storage as a scheduling aid.

In addition to low temperatures, the role of light and relative humidity (RH) has been examined to assess potential for manipulating vegetative plant growth.

The study involved:

- Literature search and review, covering all the above subject areas
- Consultation with members of the industry, in the UK and abroad, who have had experience of using cold stores to manipulate growth.
- Cost:benefit analysis to determine the economic viability of the technique including the economic differences between the storage of finished plants as compared to the storage of liners.
- Review of cold store types available with recommendations for the most suitable stores

Recommendations are made for follow-up research work, where the results of the review suggest that an economic benefit can be achieved through using low temperature as a scheduling aid.

1.3 Summary of the Project and Main Conclusions

There are many benefits from the use of cold storage in the production of container-grown HONS. In summary, these are as follows:

- Delays flowering and growth in a large range of species, therefore enabling crops to be scheduled to meet customer demands.
- Provides frost protection for frost-sensitive species.
- Reduces labour input in terms of trimming and holding plants.
- Avoids the problems of culturally induced tenderness typical on crops grown under protection.
- Frees up valuable glasshouse and polytunnel space over winter.
- Plants can be stored close to point of despatch so easing labour pressure during the busy despatch period.
- May induce hardiness in some cases.
- Can be used to schedule flower initiation when used in conjunction with photoperiod lighting.
- Can improve crop uniformity by holding crops at a similar growth stage.
- Can be used to ‘hold’ plugs or liners waiting to be potted.
- Can maintain quality in plants loaded and ready for despatch and enable orders to be made up further in advance of the despatch date.

As can be seen from this list cold storage has many applications across a wide range of situations, species and crop growth stages. The review of how much growers use cold storage has highlighted that plants that do not take well to cold storage are the exception rather than the rule. Dutch growers store all except the most disease susceptible species. However, where the process becomes more delicate is when it comes to storing finished plants in bud or flower. Cold temperatures at this particular growth stage can lead to flower drop and more information is required on how to maintain flowers under these conditions.

Scheduling should lead to reduced wasteage. The benefits of this will be more apparent in some years than others but with the variable nature of the weather the facility to hold plants back could make the difference between profit and loss on some batches.

Cold storage is widely used in the production of bare-root crops and, of course, for maintaining quality of fruit and vegetable crops following harvest. As these applications are widely used there are significant levels of expertise in the technology within the UK with companies specialising in the storage of horticultural material. However, storing container-grown plants for long periods is still new to most of them and some of the fundamental differences between this type of storage, and other types, still need to be learned.

1.4 Financial Benefits

The cost:benefit analysis shows that cold store construction is a significant investment for a nursery but the financial benefits can outweigh this cost. It is not possible to carry out a cost:benefit analysis on all the potential benefits of cold storage but even a simple comparison using cold stores, as opposed to glasshouse floor space, showed a benefit for small and medium sized plants. Table 1 shows this comparison for a square metre of cold store and the equivalent area of glass. The cold store cost (£21.35/m^2) is based on an average of the cost of different stores assessed in the project and running costs.

Table 1 – Direct Area Comparison between Cold Store (CS) and Glass

Plants or pot size	No. of layers on trolley	Cost of CS area	Cost of Glass area	Difference	% Difference
Large Plants	2	£21.35	£9.12	-£12.23	-57.28
3 Litre	4	£21.35	£18.24	-£3.11	-14.57
	5	£21.35	£22.80	£1.45	6.79
9 cm	7	£21.35	£31.92	£10.57	49.51
Plugs	9	£21.35	£41.04	£19.69	92.22

The benefit was even clearer when it came to using the store to improve the 'saleable yield' of the crop (Table 2). In this way plants are stored in order to delay flowering. An example would be the storage of 3 litre container-grown plants. If the store was used to hold just one crop, long enough to ensure that at least 10% more of it would be sold (than if it had not been held in saleable condition), then the benefit exceeds the cost. This is particularly attractive for crops that flower over a short period and when periods of poor weather come during peak sales times. If the store can be used for two crops then the benefits are even greater.

Table 2 – Break even yield for one crop per year

Plants or Pot Size	No. of layers on trolley	Cost	Output / m^2	% Break Even Yield
Large Plants	2	£21.35	£110.56	19.31
3 Litre	4	£21.35	£221.12	9.66
	5	£21.35	£276.40	7.72
9 cm	7	£21.35	£386.96	5.52
Plugs	9	£21.35	£497.52	4.29

It is accepted that in any industry-wide cost:benefit analysis a lot of assumptions have been made and each business should do its own analysis to ensure the figures add up for them. However, with this simple approach it is clear that a significant cost:benefit can be achieved even without using the store for many of its potential uses.

1.5 Specific Sectors that Could Benefit

Most sectors of the container HONS industry can benefit from cold storage in some way. Perhaps the most obvious way is in the storage of plugs and liners. So much depends on having these products ready in the right condition at the right time to avoid further trimming, feeding and handling. They are also relatively small and therefore large numbers can be put into relatively small storage areas. Using cold storage for plugs and liners would enable liners to be manipulated to suit potting or customer schedules. Unlike finished plants there are not the worries of flower damage.

Growers supplying large volumes of plants to multiple retailers would certainly benefit from the greater flexibility that a cold store would allow. For example, poor weather during the main flowering period for *Camellia* could lead to large numbers of plants going over and becoming unsaleable. The ability to 'hold' the plants in the bud stage can spread the flowering through the sales season and can better cope with variable weather and demand.

Cold storage has the potential to facilitate the development of mail order and export business in the UK removing the time limitations and enabling long distance transportation.

1.6 Using Cold Storage to Manipulate Growth

There are a number of key points that have arisen from this which may provide guidance on how cold storage could be used in the future to control growth, beyond the simple response of delaying flowering.

Cold stored plants may well be more stress tolerant with some form of hardiness induced into them. It may be that careful application of fertiliser, prior to storage, could also improve hardiness. It may also be that an increase in sugar levels in plant vacuoles could reduce the levels of intercellular ice and provide greater hardiness. This may mean that there are ways round the difficulties of not being able to store frost-sensitive plants at very low temperatures.

Cold storage can promote flowering in some cases. Work carried out on *Hebe* showed that plants stored at lower temperatures had more flowers than those stored at higher temperatures.

The ability to change day and night temperatures may also be advantageous. Work on DIF (the differential temperature between day and night) has shown that raising night temperature and lowering daytime temperatures can control gibberellin activity and so reduce cell growth. In addition to this the controlled environment of a cold store would enable the use of supplementary lighting which could be used to modify the red : far red ratio and so effect the phytochrome growth response.

It may be that this knowledge of the physiological responses of plants to these conditions could be used to turn the cold store into a centre for crop growth manipulation. With further research it may be that use of techniques evolving from the knowledge of the phytochrome and gibberellin responses in plants could alleviate the present difficulties involved in storing some species when in bud or flower.

There is still a lot to learn about the use of cold stores for container-grown HONS but some lessons can already be learned. Getting the temperature right and consistent is important, but what is the right temperature? The Dutch typically use –2ºC wherever they can whereas UK growers seldom store below 0ºC. Further work is required into which is the best temperature to use but the potential for growth and problems rises with the temperature.

Relative humidity (RH) is still an important factor for container-grown plants despite the fact the roots are surrounded with moist growing media. The Dutch recommend RH levels of 90% but there is a fine balance between high enough RH and the threat of disease spread from excessive moisture. Further work is required on RH to assess how critical a factor this is.

Most growers using cold storage maintain a clean environment and do not introduce diseased plants into the store. It is important that plants susceptible to diseases like *Botrytis* and *Rhizoctonia* are sufficiently protected.

1.7 Future Research Work and Action Points for Growers

A major aim when storing plants under low temperatures is to avoid chilling injury, but it is clear that species differ in their sensitivity. Studies into cold storage in the UK would enable the development of specific storage strategies for individual plant species. In most cases it would be necessary to compromise on the 'ideal' temperature as the grower will need to store several species in the same cold room. However, the evidence required to formulate successful storage strategies is not yet available and studies will need to address several parameters including species and varietal response to low temperature; optimum storage duration; and the possible requirement for a buffer period of cooling or warming to reach the desired temperature.

It is recommended that work is carried out to look at plant responses to different cold store temperatures at the same time as assessing the importance of RH. Light is another factor which could be considered as well. However, this needs to be tied into work into photoperiod to ensure the maximum benefit is achieved.

Some UK growers are already trialling the storage of a range of species an, if cold storage facilities are easily accessible, then it is recommended that growers do trial their use. However, before clear guidelines can be given, on how to use cold storage for different species and how to avoid any potential problems, further research needs to be conducted.

2. Introduction

2.1 Background and Potential Benefits to the Industry

Accurate scheduling is becoming increasingly important in the production of hardy nursery stock in the UK, particularly for those growers who supply garden centres and multiple retailers such as supermarkets and the DIY 'sheds'. These outlets are continuing to demand smaller amounts of product on a more regular basis, and high volumes at specific marketing periods throughout the year e.g. Easter, spring bank holidays, etc. However these represent narrow windows of opportunity, and adverse weather conditions at these specific times can cause considerable losses through unsold product. The retailer is rarely willing to carry these losses.

The recent experience of a grower based in the south of England highlights this issue: when a customer requested a delay in marketing of three weeks the nursery reluctantly agreed and attempted to hold the plants. However, this proved to be difficult and the customer subsequently rejected a large proportion of the stock, resulting in losses to the grower of over £10,000.

An increasing amount of nursery stock is being produced under glass. The use of cold stores to hold stock could increase the throughput of these structures considerably, enabling a higher return per m^2 of glass each year. Labour inputs could be utilised more effectively by removing some of the peaks and troughs of seasonal production. The ability to hold liners would enable the development of scheduled potting regimes, which would also increase throughput on the nursery.

Successful restriction of growth would enable season extension through delayed vegetative and reproductive growth. It will be possible to manipulate flowering with low temperatures and to extend periods of marketing in flower or in bud. Careful consideration of flower initiation will be required. It may be necessary to store as liners those species that initiate and flower the same year, e.g. *Cistus, Fuchsia* and some *Hebe.*

Those species that form buds in the previous year could be stored either as liners or as finished product, e.g. *Rhododendron, Azalea* and *Camellia.* The technique would allow the grower to hold plants at specific growth stages and thereby improve crop uniformity; and to build up the large volumes of stock required for times of maximum demand.

Possible future developments in the export of nursery stock from the UK will depend on storage techniques to facilitate the process and ensure quality plants at the point of sale.

Low temperature storage is a technique which is already applied in many areas of the HONS industry, for example, storage of propagation material, bare root trees, hardwood cuttings, hedging material and rootstocks in the rose and fruit sectors. Its application for cold storage of container-grown nursery stock is less well understood. This project seeks to assess the feasibility of cold storage for this purpose.

2.2 Scientific and Technical Objectives

The main aim of this review is to assess the feasibility of using low temperatures to suppress growth and development in nursery stock species. Subsequent plant quality is of the utmost importance to growers and it is essential that plants do not suffer any adverse long or short-term effects as a result of using cold storage as a scheduling aid.

In addition to low temperatures, the role of light will be examined to assess potential for manipulating vegetative plant growth. It would be of particular interest if light levels could be used in conjunction with low temperatures to increase the degree of control and/or enhance plant quality. The effects of light and temperature on flowering in nursery stock subjects will also be considered.

Relative humidity is also an important factor to consider in cold storage. Items stored in a domestic refrigerator will loose moisture and commercial cold stores are no different. Understanding acceptable humidity thresholds and methods for maintaining them is an important objective.

2.3 Approaches to the Programme

The study involves:

- Literature search and review, covering all the above subject areas
- Consultation with members of the industry, in the UK and abroad, who have had experience of using cold-stores to manipulate growth.
- Cost:benefit analysis to determine the economic viability of the technique including the economic differences between the storage of finished plants as compared to the storage of liners.
- Review of cold store types available with recommendations for the most suitable stores

The report makes recommendations for follow-up research work, where the results of the review suggest that an economic benefit can be achieved through using low temperature as a scheduling aid.

2.4 The Benefit to Growers

In many cases cold storage will require a significant investment for any growers wishing to use it. It is important that the basics of cost:benefit are considered before embarking on such an investment. This project pulls together the available information from around the world to help growers assess how it may benefit them. This research provides a clear baseline for further work into the detail of which species to store and how best to do it.

3. Methods in Plant Scheduling

A considerable amount of work has been carried out in the UK funded by the Horticultural Development Council (HDC) into the scheduling of bedding plants. The work has concentrated on temperature manipulations, irrigation and fertiliser control, photosensitive cladding materials and novel techniques such as brushing. Work on Hardy Ornamental Nursery Stock (HONS) has been carried out abroad and more recently in the UK focusing on roses (Burgess, 1996) in HDC Project HNS 65 and on herbaceous perennials (Monaghan, 2000) in HNS 103. Various parameters effect plant growth and development and, when understood, can be utilised in crop scheduling. This section summarises the main methods in use and goes on to provide greater detail in the use of cold storage which provides particular control over temperature and light.

3.1 Nutrient Restriction

High levels of fertiliser in a plug media will promote rapid growth, even before the first true leaves emerge (Styer & Koranski, 1997).

Where phosphorous availability is restricted plant growth will be reduced. Phosphorous *deficiency* can severely arrest growth and plugs may not grow out following transplanting. However, the response is species-specific and the strategy also reduces plant weight, leaf size and overall quality. The technique is used in plug production to hold back batches of plants. The manipulation of liquid feeding regimes is used to restrict growth and final plant height. HDC Information Sheet 01 / 02 (Bragg & Carey, 2002) outlines recent research in Denmark into the benefits of reducing phosphorus in the production of protected ornamentals. This was found to be successful with the help of a 'P-buffer' called Compalox®. Reducing phosphorus increases the plant root to shoot ratio so reducing foliage growth.

3.2 Drought Stress

Irrigating routinely at the point of wilting leads to a reduction in cell expansion and plant growth, producing a more compact plant. The leaves and stems of many species are often thicker under drought conditions, and root growth is improved. The main drawback can be a greater risk of foliage scorching. In addition, low moisture levels can cause stunting and delayed flowering. In certain species such as *Celosia* and French marigold, low-moisture stress causes premature flowering in the plug tray (Styer & Koranski, 1997). However, work funded by HDC in the UK has demonstrated the success of this technique, particularly in Petunias.

A current HortLINK project on water (Cameron *et al*., 2002 – HDC Project HNS 97), is also investigating ways of reducing the amount of water applied in order to control growth and improve irrigation efficiency.

3.3 Temperature Stress

Storage of plants at low temperatures is not new. Cold stores are an established feature for field-grown nursery stock producers. Such stores enable growers to lift field-grown stock in the autumn, before the ground gets too hard or wet, and hold it in its dormant state through to sale in the spring. This practice is based on the proven principle that plant lifting and replanting during dormancy is less damaging to the plant than disturbance during active growth. Although considerable volumes of field-grown stock are still produced in the UK, and marketed as bare-root material, the biggest change over the last 40 years has been the move to container production. This removes the need to lift plants at a certain time and provides a crop that can be available for sale year round. Relatively little work has been carried out on cold storage of container-grown HONS. However, many lessons can be learned from the work conducted on field-grown crops and more recent work on herbaceous perennial scheduling.

Temperature Stress for Bare-Root Production

Commercially produced trees, for both the ornamental and forestry markets, are still largely produced in the field. Lindqvist (2001) showed that the length of time that bare-root trees are stored (in this case Silver Birch and Common Oak) is less important than the time of lifting. In this study four lifts of trees were carried out at four week intervals, between autumn and early winter. Each lift was stored for 90, 135 or 180 days. Tree mortality reduced with the trees lifted the latest and the length of storage had no effect. However, for trees lifted in the autumn deterioration in store increased the longer they were stored. Lindqvist (2001) suggested that the exposure to low temperatures is probably an important factor in the development of stress tolerance in bare-root plants of Silver Birch and Common Oak.

In their guidance note on the cold storage of broadleaved nursery stock Kerr & Harper (1994) suggest that bare-root stock should be bagged to avoid desiccation but that cold storage is not detrimental to survival in comparison with fresh lifting. They recommend it for bare-root stock required at unavoidably late periods or for out-of-season planting. Garriou *et al.* (2000) do not completely support this advice. Their experiment looked at the effect of desiccation during cold storage on planting stock quality and field performance in forest species *Quercus robur*, *Quercus rubra* and *Pinus nigra*. They concluded that it is better to lift seedlings between January and March, ensuring planting soon after lifting, than to lift in autumn and cold store until spring. They claimed that the increased desiccation in storage, due to water loss from the roots, reduced seedling quality. However, the ideal of lifting and planting straight away is seldom practicable and where the root protection measures encouraged by Kerr & Harper (1994) are implemented the potential for desiccation and subsequent poor establishment is minimised. Careful storage, that ensures minimal water loss from the roots, is important and was confirmed by Bates & Niemiera (1997).

In North America and Canada there is interest in using cold storage to develop cold hardiness in nursery stock. This would enable more northern parts of the country to grow less cold-tolerant plants. Studies have considered the state of the plant before it enters dormancy. In a review of carbohydrate sources and sinks in woody plants Kozlowski (1992) suggests that an accumulation of sugars in the autumn has been causally related to cold hardiness. It may be that sugars increase hardiness by accumulating in vacuoles and reducing the formation of intercellular ice so causing changes that increase tolerance to freeze-induced dehydration, and diluting compounds such as electrolytes that are potentially toxic to membranes. Therefore bare-root plants going into store should have received adequate nutrition and it could be argued in some cases that extra fertiliser, prior to lifting and storage, will improve hardiness.

From this research it can be seen that cold storage of bare-root woody plants, during dormancy, provides an ideal way of ensuring that customer demand for these plants is met year round, even when field lifting is not possible. With adequate root protection (Kerr & Harper, 1994) and relative humidity levels (Balls, 1987) during storage then there is no reason why stored bare-root plants should not establish well.

Herbaceous perennials, grown in the field, are also stored through the winter so crowns can be planted in the spring. Perennials are typically stored at <1ºC. One concern over the storage of bare-root herbaceous perennials is the tendency for moulds to develop. Some growers have dipped crowns into a fungicide prior to storage but Hanchek *et al.* (1990) suggests that fungal growth is best prevented by proper harvest and storage procedures rather than chemical treatments that add to production costs and can damage plant material. Hanchek & Cameron (1995) looked at harvest date and storage quality of herbaceous perennials. They found that survival rates were highest for those lifted the latest and stored for the longest (i.e. up to seven months) at 0ºC. They also found that the absence of storage mould does not necessarily indicate better plants. These moulds are often just secondary or superficial pathogens.

Temperature Stress for Container-Grown Ornamentals

Most work that has been done on temperatures for container-grown ornamentals has been with a view to programming flowering and extending growth and flowering seasons. By far the majority of this work has been carried out on herbaceous perennials (e.g. Armitage & Garner,1999; Iverson & Weiler, 1994). Most of these studies were linked closely to photoperiod and the relationship between temperature and photoperiod. This relationship has been developed further in HDC project HNS 103a which is presently underway. One thing that is clear from the literature is that there is no consistent response to temperatures or photoperiod between different species, or even cultivars. Iverson & Weiler (1994) tried to group perennials that they wanted to force, in terms of their cold requirement. They found that exposure to cold had three main effects:

- Cold may be necessary to release plants from dormancy.
- Cold may trigger flower induction (i.e. vernalisation).
- Cold can accelerate and synchronise growth, increase stem length or improve flower quality.

They divided the perennials they tested into three main groups and recommended forcing measures as follows:

1. Early spring flowering plants that have a cold requirement but lack a daylength requirement are best forced in the glasshouse after receiving 12 weeks of cold.
2. Late spring/early summer flowering plants that may or may not have a cold requirement, and are probably long day plants, are best forced in the glasshouse under long day conditions after receiving six weeks cold.
3. Late summer flowering plants that do not have a cold requirement, but are still long day plants, are best forced in the glasshouse under long day conditions.

Most woody plants go into dormancy with the onset of short days and come out following the fulfilment of the cold requirement but this is not necessarily the case for herbaceous perennials. Heide (2001) studied *Sedum telephium* and found that it did not require cold to release it from dormancy and that long days alone were sufficient. Armitage & Garner (1999) exposed six different taxa of herbaceous perennials to treatments involving 0, 4, 8 or 12 weeks of cold (2-3ºC) followed by long or short day photoperiods. They found that cold was not necessary for the flowering of any of the taxa they tested and that there was no interaction between photoperiod and cooling. However, they considered that this finding could not be applied across all herbaceous perennial species. Other work has shown that photoperiod response can be influenced by cooling and responses may vary at different stages of plant development. In this study cooling accelerated flower forcing regardless of photoperiod. They concluded that 4-8 weeks cooling was better than 12 weeks and grouped perennials into three categories for commercial use:

1. Day neutral, cooling beneficial: e.g. *Myosotis, Arabis*
2. Quantitative long day plants, cooling beneficial: e.g. *Anchusa, Gypsophila*
3. Qualitative long day plants, cooling beneficial: *Campanula, Catananche*

HDC Project HNS 103a has identified daylength, temperature and light as the key factors affecting growth in perennials. The experiment aims to group perennials in terms of whether or not cold is required for flower initiation, how much cold is required and whether or not there is a daylength effect. This will show whether the tested plants require a critical cold period for initiation, whether cold is just beneficial for initiation or whether cold is unnecessary. HDC Project HNS 103 outlined screening protocols that growers can use on the nursery to test their own crops to establish which group they fall within.

Bailey & Scoggins (1996) found that some perennials do need cold treatment to initiate flowers but the plants must be mature enough to perceive the cold. For example, Columbine should have 12 leaves, *Lavandula* 'Munstead' should have 40-50 leaves (20-25 nodes) and *Coreopsis* 'Sunray' should have 16 leaves (8 nodes). This reinforces previously cited work indicating that cold requirement response increases in more mature plants. According to Runkle *et al.* (1998) photoperiod control and cold storage are important to complete, rapid and uniform flowering in *Phlox paniculata*, with growth of cooled plants being more vigorous than uncooled plants.

Little work appears to have been carried out on ornamental shrubs although Whitman *et al.* (1996) tested *Lavandula angustifolia* in a 5°C cold store for 0, 5, 10 and 15 weeks. They found that the longer storage periods increased flowering and increased the speed to visible bud stage. This species was tested for the purpose of essential oils production and it was recommended that plants grown for this purpose should be given 10 weeks at 5°C when they have more than 11 nodes.

Noack *et al.* (1996) looked at the effect of low temperature on the flowering of three cultivars of *Hebe*. They found a variation in response between cultivars but flowering was promoted by chilling. Three temperatures were used (forcing 19ºC, cool 9.5ºC and cold 3ºC). They were kept in these treatments for 0, 3, 6, 9 and 12 weeks. Plants were all forced at 19ºC for 12 weeks after each treatment. The lower temperatures led to an increase in flowering for all three cultivars. The total time to the point of flowering increased with the increased duration of chilling, but the time from the end of chilling to flowering was less in those that had been cooled. A similar result has also been observed in *Hydrangea*. This finding shows that although chilling can delay flowering, plants flower much quicker once they are removed from the low temperatures.

There is relatively little published information on the cold storage of container-grown HONS. Some UK growers do practice it but it is largely based on experience rather than scientific research. The work on herbaceous perennials, described above, offers potential for that crop but is likely to require a clear understanding of the growth response for each species as well as facilities to provide temperature and daylength control. However, the fact that some do cold store their container-grown stock, and have done for many years in some cases, is good evidence that the method works, at least for some crops. Section 6 considers this experience in cold storage for container-grown HONS with a view to assessing the potential for more wide-scale commercial application.

3.4 Light Stress

Photoperiod was discussed in some depth in section 3.3 but little information is available on light levels required for the storage of container-grown HONS. Clearly this is not an issue for bare-root material in its dormant state but for crops in leaf, or even flower, it can become much more critical.

Where container-grown stock is stored commercially the only lighting in the store is there to enable staff to see and is usually switched off when nobody is in the store. Light is a limiting factor for photosynthesis. In the dark stomata will close and respiration will be reduced, this will all help to hold the plants as is the purpose of a cold store. Some lighting may be required although the pros and cons of this have not been explored for container-grown nursery stock.

4. Crop Sensitivity

Once investigations begin into how plants respond to temperature it is not long before it is clear that temperature affects many different components of plant growth. This section considers some of these different physiological aspects involved in growth with a view to understanding how they may impact on temperature controlled storage of nursery stock.

Studies into differential temperatures have been used to address this issue. Differential temperatures are commonly referred to as DIF and have been used to control growth in growing conditions where this can be achieved. Negative DIF requires night temperatures to be higher than day temperatures (which can involve high energy inputs to achieve) compared to positive DIF representing the more typical growing conditions of higher daytime temperatures than night temperatures. Not all researchers are agreed on whether it is the difference in day and night temperatures that is important or simply the mean diurnal temperature (Pearson, pers com.).

4.1 Gibberellins

Gibberellins are a group of hormones with responsibility for tallness. The stem of a tall plant contains more biologically active gibberellins (GA) than does the stem of a dwarf plant. As GA levels increase so cells elongate which can appear as stretching or bolting on some crops. Zieslin & Tsujita (1988) used applications of GA to overcome the cell elongation effects caused by a negative DIF regime (night temperature higher than day temperature) used in the growth of lilies. Similarly, applications of GA to *Campanula isophylla* Moretti and *Lycopersicon esculentum* L. overcame the inhibition of cell elongation under negative DIF.

GA inhibitors (i.e. plant growth regulators) can be applied to prevent cell elongation and are frequently used in pot and bedding plant production to ensure well shaped plants. The effects of negative DIF can be accentuated by applications of GA inhibitor - Erwin *et al*. (1989) used ancymidol on lilies grown under a positive DIF regime (day temperature higher than night temperature) and demonstrated a greater decrease in internode length than in those plants grown under negative DIF.

Temperature affects both the levels of GA and also the ability of the plant tissue to respond to GA.

4.2 Phytochrome

Photomorphogensesis describes the developmental response of plants to light. When a seed emerges above soil level this response occurs changing growth to produce a structure suitable for above ground conditions. Among the different pigments that can promote photomorphogenic responses in plants, the most important are those that absorb blue light and red light. Phytochrome is the red light photoreceptor. Temperature and light quality can interact and this provides evidence to support phytochrome involvement in controlling plant development (Moe & Heins, 1990). Phytochrome is found in two forms prompted by two different wavelength bands of light; red light (650-680nm) and far-red light (710-740nm). The Pr form of phytochrome is prompted by red light and the Pfr form by far-red. One form can be converted to the other in response to exposure to the different light bands. In most cases Pfr is the physiologically active form and therefore exposure to the different light bands will have different growth responses. The ratio of R : FR is the key determinant. Illumination with low Red : Far-Red (R : FR) light , provided by incandescent light during the night, can overcome inhibition of cell elongation in *Campanula isophylla* grown under negative DIF and can therefore promote growth. Conversely, high R : FR applied during the night using fluorescent light enhanced the inhibition of cell elongation.

This interaction suggests that phytochrome may be the site of perception by the plant of the variations in temperature regimes, or it may be involved in the chain of reactions that produces the growth effects.

Indirect evidence also supports the involvement of phytochrome in thermomorphogenesis. Plants grown under positive DIF appear to be morphologically similar to plants irradiated with a low R : FR ratio - long internodes and an upright leaf orientation. Plants grown under negative DIF resemble plants irradiated with a high R : FR ratio of light - short internodes, reduced plant height and a horizontal leaf orientation.

This background highlights a potential role for the control of growth using red and far-red light under temperature controlled conditions.

4.3 Carbohydrate Status

Work on *Lilium longiflorum*, published by Miller *et al.* (1993) investigated the effects of temperature on leaf, flower and stem carbohydrate levels. It was found that plants grown under a positive DIF regime had lower levels of total soluble carbohydrates (TSCs) in all of these organs than plants grown using negative DIF - 39-46% reduction in both the leaf and stem, and 10-13% in the flower. This is significant in the postharvest performance of some species, for example, it is likely that lily leaf chlorosis may be advanced by low TSCs.

The phenomena of low TSCs has not yet been fully investigated, but the enzymatically driven dark reactions in photosynthesis are strongly influenced by temperature and it is thought that low TSCs could be connected to a lower rate of carbon fixation. Furthermore, increased rates of dark respiration may deplete the carbohydrate pools.

This is a concern for cold stored crops where low day temperatures could lead to a reduction in TSCs. This may just mean that plants have to ‘catch up’ once they return to positive DIF conditions or it may have a longer term effect on plant quality due to this reduced photosynthetic activity during storage.

4.4 Cell Elongation

Erwin *et al.* (1994) demonstrated that cell elongation, rather than division, was responsible for the increase in internode length in *Lilium longiflorum* Thunb under normal temperatures. They showed that as day temperature increased, relative to night temperature, so the length of stem parenchyma cells, and stem and leaf epidermal cells increased. No increase was observed in the width of cells or the number of cells per internode.

Thermomorphogenesis (the relationship between temperature and plant development) is a complicated area of crop physiology and it seems clear that there is no simple explanation of how cold storage may effect plant development. However, an understanding of how gibberellins and phytochrome may respond at lower temperatures may prove to be useful when applying mechanisms for maintaining plants in cold storage. The fear of crop deterioration (particularly of flowers) in store is a worry for some that may consider storage as an option. It may be that the information available within this section of the report could provide a baseline for further study in this area.

5. Low Temperature Stress

The effect of temperature on plant growth and development is a highly complex interaction of organs, such as leaves, stems and flowers, which can each respond to temperature differently. For example, the rate of leaf initiation in chrysanthemum is related to the mean diurnal temperature, but stem internodal extension is a complex function of day and night temperature. Flowering can also be described by a simple linear relationship with mean diurnal temperature, however, the response has been shown to vary widely between species and cultivars.

5.1 Chilling Injury

Under low temperature storage regimes, a main objective would be to avoid detrimental effects such as long term photoinhibition and cell membrane collapse, symptoms commonly referred to as chilling injury.

The earliest and most common visible symptom of chilling injury is water loss which results in severe wilting during the period of exposure. If this period is not too long or the temperature too low, the effects are reversible and turgor can be recovered (Creencia & Bramlage, 1971). If severe damage has been sustained, cell membrane integrity is lost and dessication, necrosis, or death of the whole plant will result (Rikin, *et al*., 1979; 1976).

Wilting during chilling is produced by changes in membrane permeability which allow water and soluble materials to leak out into the intercellular space, from where the water is lost through evaporation (Wright, 1974; Wright & Simon, 1973).

Chilling exposure will also result in a reduced respiration rate and a decrease in substrate oxidation by the membrane-bound enzymes of isolated mitochondria (Stewart & Guinn, 1971). Enzymes involved in the TCA cycle also appear to be sensitive to low temperatures, particularly malate oxidase (Stewart & Guinn, 1971).

Respiration rate may increase during exposure to low temperatures (Wilson, 1978) and will often increase dramatically when temperatures subsequently rise on transfer to a warmer environment (Sasson & Bramlage, 1981).

Photosynthesis of chilling sensitive plants has been shown to decrease following exposure to low temperatures. Specifically, membrane-localised chloroplast activity declines in chilling sensitive plants (Lasley *et al*., 1979; Smillie & Nott, 1979;Yakir *et al*., 1986).

Photoinhibition of photosystems as a result of low temperature involves decreased rates of oxygen evolution and electron transport in photosystem II. The effects are not as dramatic in those plants acclimated to low temperatures (Garab, 1998).

Alterations in flower morphology can occur as a result of severe chilling. Hwang (1999) observed several abnormalities in *Oryza* including extra stigmas, double ovaries and growth distortion in anthers.

The genetics of chilling sensitivity has been studied intensively over the last 10 years, with a view to engineering cold tolerance in crop plants. A comprehensive review by Guy (1999) details aspects of this area of research including inducible low temperature stress tolerance; low temperature stress proteins; antifreeze proteins; cold shock domain proteins; perception of low temperature; and the prospects for modification of temperature stress tolerance.

6. Cold Storage of Hardy Ornamental Nursery Stock in Practice

6.1 Types of Cold Store

There are a number of different types of cold store in use by growers. Some growers have begun by trialling cold storage using a second-hand lorry refrigeration unit before going on to build a full size store. Successful long term storage needs a combination of low temperatures and high relative humidity (RH). The recommended temperature for most species (when bare-root) is 0°C, with a RH approaching 100% to prevent drying out. This is not quite so critical for HONS in containers (which should be in moist growing media) and very often in leaf, or even flower. The options for a purpose built store are as follows (Balls, 1987):

Direct Expansion (DX) Stores – This is the system used in most conventional cold stores: so called because the store air is in direct contact with the refrigeration coil. These stores are relatively cheap to install and are normally the only type available for renting. The main disadvantage of a DX store is the drying effect of the refrigeration coil, which can excessively lower the relative humidity (RH) within the store and cause desiccation. For these stores to be used bare-root material should have roots wrapped or, without some means of maintaining the humidity, they should only be used for short term storage.

John Richards Nurseries in Herefordshire has recently installed a 470m^2 DX store (Richards pers com.). The store was built by the nursery using different contractors to fulfil different aspects of the construction. The store is based on a steel framed building with plastic coated steel profiled sheets on the outside and insulating foam on the inside. A cooler unit is installed inside the store with fans to maintain air movement and prevent leaf wetness. The store maintains its target temperature of 1°C through most of the winter but by April the cooler struggles to keep the temperature below 3°C.

Jacketed Stores – In this type of store the product is separated from the refrigeration coils by a waterproof membrane, so any drying effect of the evaporator coil cannot be transferred to the stored material. The store consists of a conventionally insulated outer shell and a metal-walled inner shell, constructed so that the air from the cooler can circulate in the space (jacket) between them. The cooling unit and circulation fans are sited within the jacket airspace, with controls to maintain the correct storage temperature. Heat is conducted from the nursery stock in the inner shell through the metal walls to the jacket; the only air circulation within the shell being provided by convective currents.

Hillier Nurseries Ltd. constructed a jacketed store in the late 1970's (Woodhead & Hooker pers com.). This store, still in use by the nursery, is approximately 30 x 20 x 4 metres (600m^2) with a 1 metre wide cavity (jacket) around the building. In contrast to the problems with bare-root material they find that RH gets too high and even leads to problems of droplets from the roof dripping onto the plants in store. To try and overcome this problem fans have been installed.

Wet Air Cooling – In this system the store air is cooled by direct contact with chilled water. By using water as the cooling medium, the store air does not lose moisture and it is impossible to cool the store below freezing: so frost sensitive species will be protected. The store air is drawn through and cooled in a heat exchanger. This is a tower filled with a honeycombed material to break the flow of chilled water, so exposing the maximum water surface area to the air.

6.2 Main Uses for the Cold Stores

The use of the cold store varies between businesses depending on the crops they are producing and the storage facilities they have available. The main uses by UK growers explored in this research are as follows:

Storage of Bare-root Material

This method is still widely used in the nursery stock sector for both bare-root trees and herbaceous perennial crowns. Considerable research has already been done in this area but is not the focus of this review.

Storage of Cutting Material

Cutting material, especially when imported, cannot all be stuck into plug trays immediately. Darby Nursery Stock Ltd store cutting material for anything from one day to two weeks at <4^{o}C in a direct cold store without a detrimental effect (Hazell pers com.).

Storage of Plugs

Darby Nursery Stock Ltd. have experimented with the storing of plugs to help free up valuable glasshouse space and slow growth to ensure they are not over-grown when the time for potting comes (Hazell pers com.). Plugs are introduced into store during December and January and held until March or April. Direct cold storage was used at <4^{o}C. The results were variable with some losses across all the species tested (*Potentilla*, *Spiraea*, *Weigela*, *Lonicera*, *Polygonum*) with many not growing away after potting as quickly as had been hoped. The company believes that there is considerable potential for more research in this area as plugs can be stored densely within a cold store.

Storage of Plants for Shows

Many nurseries exhibiting at major garden shows like Chelsea and Hampton Court need to have plants at their prime during a season when they may not naturally be so. Cold storage provides a method of holding plants that can be brought out of the store prior to the show in time for them to leaf or flower as required. Although this practice enables the identification of a range of plants that do (or do not) store well it is never going to be a major feature of commercial production.

Storage of Liners and Finished Plants

The main emphasis of this project is the storage of finished plants. HONS growers store finished plants for the following reasons:

- To delay flowering or growth
- To initiate or delay initiation of flowering
- To provide frost-free over-wintering environment
- To free up valuable glasshouse or tunnel space

Hillier Nurseries Ltd. use their cold store as a means of delaying flowering and growth in a range of species whereas John Richards Nursery use cold storage to free up glasshouse space and provide a frost-free environment for sensitive species. Liners can be stored to delay growth to meet potting schedules.

6.3 Species Stored Successfully

This section identifies the different nursery stock species currently stored by some growers in the UK as well as some specific points where information has been provided.

Hillier Nurseries Ltd.

Storage to enable scheduling

Plants are introduced into the store in 3 litre pots on danish trolleys. Storage is at 1-2ºC. Species stored are as follows:

Japanese Azaleas

All varieties are routinely stored for up to 3 months, although 2 months is more typical (mid March – late April). Plants are stored in order to extend the time when Hilliers can supply plants in flower. Some have already been in cold storage in Holland before coming to the UK. Plants must be stored before bud colour can be seen and temperatures must not be permitted to rise during storage as growth will be stimulated. If there is soft growth or flower present then *Botrytis* is likely to occur. But if introduced during the right stage of dormancy then losses are not experienced and plants come out looking as good as they went in.

Philadelphus coronarius 'Aureus'

These are introduced into the store in mid February and stay until May. The purpose of storing these is to meet the schedule imposed by a multiple retailing customer. Cold storage provides the right balance for this crop because if left outside then the plants would be damaged by frost and if left under protection they would grow too quickly. When required, the plants are moved out into a Spanish tunnel. No detrimental effects of storage have been observed.

Hydrangea

Most varieties (mainly lacecaps) except *H. involucrata* are stored. These plants can be for any number of customer orders so batches are taken from the store as required. The reason for storage is the same as for the *Philadelphus* above. The ideal environment would be an open-top glasshouse where the roof could be closed during frost. As this facility is not available the store is the next best. *Hydrangea* are left outside in the autumn until frosts have knocked off the leaves and flowers have initiated. The plants are brought into the store around Christmas time and most will come out between late April and early May (i.e. up to 4 months).

Pieris

These are not routinely stored although some varieties are usually stored (i.e. *Pieris* 'Forest Flame' and 'Flaming Silver') in order to hold back the first growth flush. If these plants are to be stored then they **must** go in before growth has started. They can be stored for up to 2 months.

Cytisus (Brooms)

Again, these are not stored as routine and tend to only be stored if the sales season is wet and they need to be held until a time when sales will be higher. Brooms can be stored, even when colour is showing in the flower bud, without any detrimental effect.

Disease

Botrytis is the only disease that has been observed on plants in storage. To combat this routine spraying of the plants is carried out in the stores as soon as leaf growth appears.

Fortnightly sprays (using the lance attached to the boom sprayer) are done alternating the usual *Botrytis* fungicides such as Octave (prochloraz), Rovral WP (iprodione) and Elvaron WG (dichlofluanid).

Dead leaves are removed from plants before going into store to reduce the potential for disease establishment.

In addition to these measures the stores are swept and washed out once each year. Disinfectants are not used but the company believes it would be beneficial to apply Jet-5 after the store has been used.

Watering

Very little watering is required if the plants are introduced to the store 'moist'. Water application during storage is avoided where possible as this encourages *Botrytis*. However, plants must not be allowed to dry out or desiccation will occur.

General Comments

Hilliers do not experience a reduction in plant quality from using the cold stores as long as the conditions, highlighted above, are observed. The only plants stored, other than those mentioned above, are those used for the Chelsea displays and almost anything will be stored for this purpose. The need for store space for Chelsea puts pressure on the space available for general nursery purposes. The stores are monitored regularly although a weekly check would probably be sufficient.

There is the perception that flowers open more quickly after storage than they do under normal conditions. However, there is no evidence to prove that this is due to the cold treatment itself compared to the fact that growing conditions (i.e. light and temp) are increased by the time the plants leave the store (i.e. early summer).

John Richards Nurseries Ltd.

Cold storage is an important aspect of the production cycle for John Richards Nurseries Ltd. enabling valuable tunnel space to be freed up and frost-sensitive plants to be kept in a frost-free environment. Most of the stored plants are brought into the 470m^2 direct cooled store during November and December, starting in November with the most tender species. Plants are taken from the store for sales up to May the following year. The store is run at 1^{o}C although temperatures are hard to keep this low during April and May. The following species are stored successfully by this nursery:

Garrya
Choisya
Daphne
Escallonia
Eleagnus
Viburnum (deciduous and evergreen varieties)
Clematis
Skimmia
Japanese *Acer*
Magnolia
Conifers (including *Cypressus and Cedrus*)
Erica 'Alberts Gold'
Prunus
Actinidia

Plants that have not been successful in storage are *Erica lusitanica* and *Cordyline*. In both these cases the stored plants died.

The nursery does not use the store for planned scheduling except in some instances. For example, cold storage can hold the buds of *Clematis montana* without damage but this is only done if the crop appears to be developing too early.

The nursery has observed another benefit from the cold storage. Stored plants are less tender than those grown in a polytunnel or glasshouse environment and therefore plants supplied to retailers will not have so much soft growth which could be killed off in frost. Naturally the cold storage tends to hold crops in a dormant state so deciduous species, stored over winter, will not be in leaf when taken from the store. The nursery deals with this by offering customers hardier stored plants, for example *Actinidia*, (with less new growth) and tunnel grown plants which will have more fresh growth. Alternatively the stored plants are taken from the store a few days prior to despatch which usually gives enough time for buds to emerge.

The nursery also believes that cold storage can induce cold hardiness in soft growth. In their own trials they showed that briefly cold stored *Pieris* 'Forest Flame' were better able to survive one night at –2ºC than plants kept under normal conditions. This is applied by, for example, putting *Clematis* due to be despatched to Yorkshire into the cold store during the night prior to despatch with the intention of inducing hardiness.

Disease

Botrytis can be a problem in store. Plants which may be likely to suffer from this are sprayed with Elvaron WG (dichlofluanid) prior to going into store and general *Botrytis* treatments (e.g. Rovral WP (iprodione)) are used inside the store itself. The nursery aims to keep humidities low enough to prevent excessive *Botrytis* spread but this is a difficult balance against the need to maintain humidities to prevent plant desiccation. No other pest and disease problems have been observed.

Watering

The nursery believes that the plants to be stored should be introduced with compost in a fairly moist state. Hand-watering does need to take place on certain plants, especially those on higher shelves which loose water as a result of being nearer to the roof fans.

General Comments

The nursery sees the benefits of the cold store as follows:

- Provides frost-free over-wintering environment.
- Avoids the problems of culturally induced tenderness typical on crops grown under greenhouse structures.
- Frees up valuable glasshouse and polytunnel space over winter.
- Stored plants are close to the point of despatch (the nursery is intending to install a conveyor belt from the store to the despatch area) so reducing labour input during the busy despatch season.
- Hardiness is induced into a number of the stored species providing customers with stronger frost-resistant plants.

Notcutts Nurseries Ltd.

Notcutts Nurseries Ltd. operate two cold stores with one at 1-3°C and the other at 5-6°C. The principle reason for storage at this nursery is to have plants ready for the various shows (e.g. Chelsea). Many species have to be scheduled in order to be in prime condition for the show. Plants are usually introduced into the store whilst dormant. The main species stored successfully in the 1-3°C store are as follows:

Azalea – stored to hold back flowering. Deciduous varieties can be stored with or without leaves but defoliation can be a problem with evergreen varieties.
Amelanchia
Prunus – different varieties respond differently to cold storage. Double flowering varieties (e.g. *P.* Kanzan) are slower (i.e. need to be taken from store 5-6 weeks prior to the show) to recover than the single flowering types (4 weeks prior to show).
Clematis
Hamamelis
Pieris
Rhododendron – these plants store well but need acclimatisation afterwards; strong sun, high temperatures or high winds can lead to leaf scorch. Once flowers have opened they cannot be stored successfully.
Camellia – bud drop can occur on these (as high as 20%) due to petiole weakening in store.

Forsythia – this species can be held for up to seven months and will still flower within three weeks of leaving the store.

Non-dormant *Laburnum* – can be stored to hold flowers if flowers are no more than one third open. However, some bud drop will still occur.

Malus

Viburnum

Herbaceous – *Dicentra*, *Brunnia* and *Polygonatum*

The second cold store, run at 5-6ºC, has been used to successfully store:

Dicentra
Euphorbia
Hosta
Polygonatum
Brunnia
Ceanothus
Viburnum (deciduous and evergreen)
Deutzia
Spiraea
Pieris
Terria
Amelanchier
Magnolia
Solanum 'Glas Nevin'
Acer
Prunus
Malus
Wisteria
Clematis montana

Disease

Botrytis is a major problem for cold stored material especially in *Viburnum*, *Clematis* (although depends on variety), foliage and herbaceous plants. Fungicide treatment prior to storage is important for susceptible varieties.

Watering

Deciduous species are generally not watered until they are removed from the store. Evergreens can dry out and in these cases careful hand-watering is applied to avoid the potential for the spread of *Botrytis*.

6.4 Cold Storage in The Netherlands, Belgium and the USA

The Netherlands

As in the UK the storage of container-grown nursery stock is not very common, particularly storage of finished plants. However, liners and plugs are often cold stored. Growers do not usually have their own store but will rent space in a large store used by many growers. The main storage company, used by growers in the Boskoop area, is Koelhuis Hillegom. This company rents out cold store space at around 10 euro (c.£6.50) /m^2/month. Growers transport the plants to be stored to the store and load them straight in on pallets.

The store runs at around –2°C which is necessary for plants being stored for periods longer than two or three months. Plants stored for shorter periods may more typically be stored at 0°C. Damage to plants is minimised by introducing them to the store once dormancy has set in (i.e. November) and reducing the temperature as quickly as possible (Schipper, pers. com). Once temperatures reach 4-5°C there is a higher risk of diseases like *Botrytis* and *Rhizoctonia*.

Dutch growers using the stores aim for humidities between 90 and 95%. To help achieve this plants are covered in polythene film and introduced with moist growing media. The stores are run without light and cooled air is recirculated around the store. They recommend that plants should not be transferred to the cold store directly from glasshouse conditions. Plants should be kept outside for at least a month to acclimatise them before introduction to sub-zero temperatures.

Species that are not hardy to these temperatures may be stored at 1°C (or 0°C in some cases). This is acceptable as long as disease pressure is low. Disease problems have been seen at this temperature and that is why plants are stored at temperatures below this if they are tolerant to it. The Dutch believe that temperatures below 0°C reduce disease problems and provide better dormancy (Schipper, pers. com).

Most species can be cold stored but the Dutch tend to avoid storing species prone to *Phytopthora* or *Pythium*. This is because frost damage can weaken the roots making them more susceptible to these root diseases when they leave the store.

Finished plants are not often stored due to the logistical costs of transporting them to and from the cold store. However, there are exceptions to this. During a recent visit to The Netherlands (Boskoop region), by the author, nurseries were visited that were cold storing *Hydrangea* in purpose built stores on the nursery. These were introduced to the store in October at 1°C in order to get them to the right stage for potting. As the leaves dropped during storage the trolleys containing the plants were removed from the store and the dead leaves removed to avoid disease spread. The trolleys were also removed from the store when any water was required. The same nursery also used the cold stores to extend the sales season for *Rhododendron* species, *Azalea* species and *Skimmia*. In these cases the plants were kept, in containers up to 5 litres, at 1-2 °C for as many weeks as required. Another nursery visited stored *Hypericum* in containers at –1 °C from November to late February to delay flowering. Dutch growers would probably use cold storage for finished plants more widely if more had stores located on their own nursery premises.

Belgium

Cold stores are not widely used in Belgium for container-grown hardy nursery stock. However, growers of the house plant Azalea (*Rhododendron simsii*) do use cold storage.

Plants are normally stored for three to four months at 1.5-3°C. Temperatures cannot be permitted to drop lower than 0°C as the plants are frost sensitive although it is not necessary to get too close to this as at 3°C photosynthesis, in the plants, has virtually stopped. The relative humidity is kept as close to 90% as possible by ensuring root systems are moist when going into store and laying wet matting on the floor (Beel, pers com). Some growers put the plants in store in the trays that they will be sold in. Water is sometimes added to the tray to help maintain humidity. However, there is a careful balance to be struck here between the need for high humidity and root death through waterlogging.

The cold conditions help the plants meet their dormancy requirement and so improve flowering after storage.

Belgian researchers believe it is important to maintain good air movement around the plants to ensure some plants do not dry out faster than others (Beel, pers com). This means it is important to keep a good distance between the cooling unit and the plants as well as the walls and roof and the plants. Growers also ventilate their stores, introducing fresh air, through the cooling unit.

USA

Cold storage of container-grown nursery stock is not widely practised in the USA (Fuchigami, pers com) except for its use in the scheduling of herbaceous perennial plants (Pyle, pers com).

One nursery that uses cold storage on a relatively large scale is Woodburn Nursery and Azaleas in Oregon. This nursery grows *Azalea* species for both the indoor and hardy plant markets (Fessler, pers com). The houseplant azaleas are stored for four weeks in the summer to break dormancy and then again through the winter and spring to delay flowering. The cold store is run at about 2°C with no light. They maintain good air movement and spray with a *Botrytis* preventing fungicide before placing the plants in the store. Relative humidity is not monitored but the condensate is drained back into the cooler to try and maintain RH levels.

Desiccation does sometimes occur and leaves can begin to drop. If this is noticed then the effected plants are removed from the store, watered up and placed back in store. To try and reduce the carbon dioxide and ethylene levels in the atmosphere the business has switched from propane to electric powered forklift trucks. The store is usually vented every day early in the morning when temperatures will not be affected too much. The nursery liquid feeds the azaleas but stops at least two weeks before the plants are stored. They find that this also reduces any damage problems.

The plants are only really stored to be able to meet customer demand periods with Mothers Day being the most important one in this case. Azaleas can be stored by Woodburn Nursery for up to six weeks and even flowering plants can be stored for up to ten days if necessary without disease problems occurring.

As the nursery has the cold store facility available it also uses it for hardy azaleas and rhododendrons when flowering time needs to be manipulated. Plants can even be placed back into store more than once although the more times it is done the more the quality does deteriorate.

The nursery confirmed the view that cold storage is not widely practised in nursery stock production in the USA, with the exception of herbaceous perennials, where the use is increasing. They see the main reason for this as the investment costs involved in setting up a cold store. However, as in the UK, they are facing increasing pressure for timeliness of production and see the cold storage facility as one likely to have increasing importance.

7. Disease Pressure in Storage

It is clear from the experience of growers outlined in Section 6 that one of the main problems when storing container-grown nursery stock is *Botrytis*. The still, damp conditions, that can exist in a cold store favour the development of this disease and the success of cold storage is dependant on successful control of *Botrytis*. Low temperatures are not sufficient to prevent *Botrytis* development. *Botrytis* can still be active at 0ºC and growth can occur around the temperatures (1-3ºC) typically found in cold stores (O'Neill, pers com.); in fact spores are able to survive for longer at low temperatures than they are in warmer environments. *Botrytis* in the store can occur either from conidia contaminating the plants directly (either present on plants when they went into store, or from affected plants or debris within the store, for example) or it can be latent infections, already present in the plants, but only expressing themselves under the conditions of cold storage. The relative importance of these two infection routes for cold-stored nursery stock is currently unknown.

7.1 Disease Prevention

To prevent conidia contaminating the plants directly it is important to maintain good hygiene inside the store itself. The spores could exist on leaf and other plant debris and making sure the store is clean is an easy way of minimising the risk from this. Dead leaves and material blowing onto actively growing foliage is another potential contamination area which needs to be prevented.

To reduce the risk of new infections arising in the store, plants should be treated with an appropriate preventative fungicide (e.g. chlorothalonil) before going into the store. It may be beneficial to maintain a spray programme while the plants are in store.

7.2 Use of Pesticides in Cold Stores

The Pesticide Safety Directorate (PSD) of DEFRA have confirmed that pesticides approved for use on ornamentals under protection can be used on container-grown nursery stock in a cold store (Appendix I). Where pesticide use is extrapolated from specific off-label approvals (SOLAs) or under the Long Term Arrangements for Extension of Use 2002, then the application is carried out at growers own risk.

7.3 Relative Humidity

Experiments with *B. cinerea* on cyclamen leaves at 10-20ºC have shown that once RH levels exceed 93% spore germination rates rapidly increase (O'Neill, pers com.). Also, lengthy periods of leaf wetness can increase the chance of symptomless infections within plants becoming aggressive. At 10-20ºC, continuous high RH periods of over three hours duration are likely to lead to *Botrytis* increase if the spores are present. The influence of humidity on infection of nursery stock subjects at very low temperatures is unknown.

If RH can be kept below 85% and leaf surfaces kept dry then this should help to prevent fresh infections developing. However, it should be noted that reducing the RH will not prevent the disease completely, it will merely prevent new infections occurring.

Fans inside the store will not directly effect the RH but they will keep the air moving and so reduce the potential for water droplets settling on foliage and leaf wetness.

Reducing the RH always raises the concern of desiccation. This is of particular concern for bare-root material where moisture is often being drawn directly from the roots. However, container-grown stock maintains its own reservoir of water in the growing media and the risk of desiccation should be lower. John Richards Nurseries Ltd. (Richards, pers com.) believe that RH should be maintained to at least 85% whereas Hillier Nurseries Ltd. would like to see RH in their jacketed store reduced (Woodhead, pers com.). Plants stored in darkness will have their stomata closed and will be using very little moisture. However, cool air holds less moisture than warm air so the environmental conditions will be considerably different to any others that the plants may have experienced. Further work is needed to assess the effect of RH on stored container-grown plants to define the best conditions that minimise *Botrytis* risk without causing plant desiccation.

8. Cost:benefit Analysis

This section aims to show by the use of simple models the cost:benefits of cold stores. The information on the cost of construction of a cold store facility is as variable as the types of cold store available. The degree of sophistication of the store will affect the overall cost and its running cost. This makes it difficult to give precise and accurate comparisons. Below are given a range of costs for a variety of cold stores. Cost has been compared on a square metre basis to simplify comparisons. The quotations for new stores ((Q) in the table below) do not include the cost of the building, in which the store is built, as this will vary depending on whether it is a new purpose-built building or an existing building. A ten-year life (pay back period) has been assumed to give an annual charge for both cold stores and glasshouses.

This section considers the cost:benefit of two main reasons why a cold store may be used; in place of glasshouse space and to schedule flowering or growth. The letters A-F in the 'Cold Store' column of Table 1 represent actual costings for nurseries that provided information as well as example quotes obtained for new stores (A and F). Full details of these quotes are outlined in Appendix II.

Table 1 – Cold Store Costings

Cold Store	Area m^2	Total Cost (£)	Cost (£)/m^2	Annual Charge
A (Q)	420	69500	165.476	£16.55
B	470	110000	234.043	£23.40
C	250	37500	150	£15.00
D (C.)	24.32	3000	123.355	£12.34
E*(C.)	26.61	4465	167.794	
F (Q)	420	58825	140.06	£14.01
Mean			**163.455**	**£16.35**

(C.) = Container, (Q) = Quotation, * hire a container each year for six months.

Table 2 – Comparative Cost for a Glasshouse

Cost (£)/m^2	Annual Charge (£)
35	3.50
50	5.00
Mean	**4.25**

Information on running costs is limited and more data needs to be collected to give accurate figures. Again these will vary according to how much the cold store is used, the temperature in the store and the ambient temperature. For comparison it is assumed that the running cost of a cold store is £5.00 / m^2, which includes an annual maintenance cost. This compares to a glasshouse kept frost-free which is c. £0.31 / m^2.

8.1 Substitution for Glasshouse

This model represents the cost comparison between a cold store and the equivalent area of glass that would take a single crop. Although cold stores are much more expensive than glasshouses it is possible to stack plants on Danish trolleys to make better use of the floor space. The higher plants can be stacked without damage then the more economic the proposition becomes.

Table 3 – Direct Area Comparison between Cold Store (CS) and Glass

Plants or pot size	No. of layers	Cost of CS area	Cost of Glass area	Difference	% Difference
Large Plants	2	£21.35	£9.12	-£12.23	-57.28
3 Litre	4	£21.35	£18.24	-£3.11	-14.57
	5	£21.35	£22.80	£1.45	6.79
9 cm	7	£21.35	£31.92	£10.57	49.51
Plugs	9	£21.35	£41.04	£19.69	92.22

Table 3 shows a comparison between a square metre of cold store and the equivalent area of glass. For the purpose of this model it is assumed that the area taken up on a trolley is equal to the equivalent area of glasshouse although it is likely that further spacing would be required in a glasshouse. No allowance has been made for paths. It is also assumed that only one crop per year is passing through the cold store.

Table 4 shows the further cost:benefit of putting two crops through the cold store.

Table 4 – Direct Area Comparison between Cold Store and Glass - 2 Crops per Year

Plants, Pot Size	Layers	Cost of CS area	Cost of Glass area	Difference	% Difference
Large Plants	2	£21.35	£18.24	-£3.11	-14.57
3 Litre	4	£21.35	£36.48	£15.13	70.87
	5	£21.35	£45.60	£24.25	113.58
9 cm	7	£21.35	£63.84	£42.49	199.02
Plugs	9	£21.35	£82.08	£60.73	284.45

Thus with small or medium sized plants there is a positive cost:benefit of using a cold store to substitute for glasshouse space. However there would be little or no cost:benefit of using cold stores to substitute for glasshouses with larger plants.

8.2 Improving Saleable Yield of a Crop

One of the advantages claimed for cold storage is the ability to hold back a crop or to retain its quality over a longer period. Thus plants can be sent out in flower over a long period or be held back if sales slow down, i.e. over a wet period of weather, without losing quality. This should increase the percentage of the crop sold (yield) and therefore the crops overall profitability. It is extremely difficult to calculate a cost:benefit because of the dynamic nature of yield, which is dependant on a very large number of factors. However, it is possible to calculate a break-even yield. This represents the increased percentage that needs to be sold to pay for the cost of the cold store. Conversely if it is possible to prevent losses less than this figure there would also be benefit. Any increase in yield above this figure will give a cost:benefit.

For the purpose of this model it is assumed that nursery output is £55.28 / m^2. All other figures are taken from previous tables. The examples given, in Tables 5 and 6, are for one or two crops per year.

Table 5 – Break even yield for one crop per year

Plants, Pot Size	Layers	Cost	Output / m^2	% Break Even Yield
Large Plants	2	£21.35	£110.56	19.31
3 Litre	4	£21.35	£221.12	9.66
	5	£21.35	£276.40	7.72
9 cm	7	£21.35	£386.96	5.52
Plugs	9	£21.35	£497.52	4.29

Table 6 – Break even yield for two crops per year

Plants, Pot Size	Layers	Cost	Output / m2	% Break Even Yield
Large Plants	2	£21.35	£221.12	9.66
3 Litre	4	£21.35	£442.24	4.83
	5	£21.35	£552.80	3.86
9 cm	7	£21.35	£773.92	2.76
Plugs	9	£21.35	£995.04	2.15

Thus for one crop per year of three litre plants the saleable yield would need to be increased by 9.66% to pay for the cost of cold storage. However, if two crops were put through the cold store then yield would only need to be increased by 4.83%. These low break-even figures indicate that it should be relatively easy to have a positive cost:benefit from using a cold store to prolong the saleable life of a crop.

8.3 Conclusion

Using these simplistic models it is possible to show a cost:benefit for the use of cold stores. However it should be noted that average figures have been used and if considering investing in such a project more accurate figures applicable to your situation should be applied to any calculation.

Consideration should also be given to what happens to the cold store throughout the year. Will it stand idle or will there be other uses that could help offset the costs? There are various options that could be considered in this respect. The store could be rented out to other businesses requiring cold store space during the summer, or simply use it as a storage shed. There may even be potential for using the store as a growing room for plants that do not like hot summers or holding plants prior to potting. All these options would add to the benefits, as opposed to the costs of the store. Conversely if comparing with glasshouses other uses of the glasshouse such as further crops should be taken into account.

However, the most cost effective application appears to be increasing crop yield by extending the peak selling period.

Other factors that should be considered include handling costs. Depending on the location of the store there may be costs involved in transferring the plants to the store. However, as at John Richards Nurseries, the layout has been designed so that the store is close to the despatch area. This means that handling costs at despatch should be reduced for plants that can be taken directly from the store.

9. Conclusions

9.1 Implications for the UK Nursery Stock industry

There are many benefits from the use of cold storage in the production of container-grown HONS. In summary, these are as follows:

- Delays flowering and growth in a large range of species, therefore enabling crops to be scheduled to meet customer demands.
- Provides frost protection for frost-sensitive species.
- Reduces labour input in terms of trimming and holding plants.
- Avoids the problems of culturally induced tenderness typical on crops grown under protection.
- Frees up valuable glasshouse and polytunnel space over winter.
- Plants can be stored close to point of despatch so easing labour pressure during the busy despatch period.
- May induce hardiness in some cases.
- Can be used to schedule flower initiation when used in conjunction with photoperiod lighting.
- Can improve crop uniformity by holding crops at a similar growth stage.
- Can be used to ‘hold’ plugs or liners waiting to be potted.
- Can maintain quality in plants loaded and ready for despatch and enable orders to be made up further in advance of the despatch date.

As can be seen from this list cold storage has many applications across a wide range of situations, species and crop growth stages. The review of how much growers use cold storage (Section 6) has highlighted that plants that do not take well to cold storage are the exception rather than the rule. Dutch growers store all except the most disease susceptible species. However, where the process becomes more delicate is when it comes to storing finished plants in bud or flower. Cold temperatures at this particular growth stage can lead to flower drop and more information is required on how to maintain flowers under these conditions.

By being able to schedule plants so wastage should decrease. The benefits of this will be more apparent in some years than others but with the variable nature of the weather the facility to hold plants back could make the difference between profit and loss on some batches.

Cold storage is widely used in the production of bare-root crops and, of course, for maintaining quality of fruit and vegetable crops following harvest. As these applications are widely used there are significant levels of expertise in the technology within the UK with companies specialising in the storage of horticultural material. However, storing container-grown plants for long periods is still new to most of them and some of the fundamental differences between this type of storage, and other types, still need to be learned.

9.2 Does it Pay to Cold Store?

Section 8 outlines a cost:benefit analysis for the use of cold storage for container-grown plants. This shows that cold store construction is a significant investment for a nursery but the financial benefits can outweigh this cost. It is not possible to carry out a cost:benefit analysis on all the potential benefits of cold storage but even a simple comparison using cold stores, as opposed to glasshouse floor space, showed a benefit for small and medium sized plants.

The benefit was even clearer when it came to using the store to improve the 'saleable yield' of the crop. In this way plants are stored in order to delay flowering. An example would be the storage of 3 litre containerised plants. If the store was used to hold just one crop, long enough to ensure that at least 10% more of it would be sold (than if it had not been held in saleable condition), then the benefit exceeds the cost. This is particularly attractive for crops that flower over a short period and when periods of poor weather come during peak sales times. If the store can be used for two crops then the benefits are even greater.

It is accepted that in any industry-wide cost:benefit analysis a lot of assumptions have been made and each business should do its own analysis to ensure the figures add up for them. However, with this simple approach it is clear that a significant cost:benefit can be achieved even without using the store for many of its potential uses.

9.3 Specific Sectors that Could Benefit

Most sectors of the container HONS industry can benefit from cold storage in some way. Perhaps the most obvious way is in the storage of plugs and liners. So much depends on having these products ready in the right condition at the right time to avoid further trimming, feeding and handling. They are also relatively small and therefore large numbers can be put into relatively small storage areas. Using cold storage for plugs and liners would enable liners to be manipulated to suit potting or customer schedules. Unlike finished plants there are not the worries of flower damage.

Growers supplying large volumes of plants to multiple retailers would certainly benefit from the greater flexibility that a cold store would allow. For example, poor weather during the main flowering period for *Camellia* could lead to large numbers of plants going over and becoming unsaleable. The ability to 'hold' the plants in the bud stage can spread the flowering through the sales season and can better cope with variable weather and demand.

Cold storage has the potential to facilitate the development of mail order business in the UK, turning production into more of a warehouse or factory type of industry where the shelf life of the produce is less critical. The technology would allow orders to be made up at more convenient times, for example, avoiding weekend working, and to prolong the life of mail order stock to alleviate the peaks and troughs of demand.

The implications of cold storage would be significant if UK growers were to move towards the export of plants into Europe. Transport is a key area in the production chain as the plants can be as much as 2 days in transit. The final quality of produce following transit would need to be guaranteed and it would be necessary to evaluate the performance of plant material under low temperature conditions in cool chain systems.

9.4 Using Cold Storage to Manipulate Growth

Sections 3 and 4 summarise the work carried out on manipulating the growth of ornamental plants. There are a number of key points that arise from this which may provide guidance on how cold storage could be used in the future to control growth, beyond the simple response of delaying flowering.

Cold stored plants may well be more stress tolerant with some form of hardiness induced into them. It may be that careful application of fertiliser, prior to storage, could also improve hardiness. The worked cited in Section 2 showed that an increase in sugar levels in plant vacuoles could reduce the levels of intercellular ice and provide greater hardiness. This may mean that there are ways round the difficulties of not being able to store frost-sensitive plants at very low temperatures.

Cold storage can promote flowering in some cases. As Section 2 explains, work carried out on *Hebe* showed that plants stored at lower temperatures had more flowers than those stored at higher temperatures.

The ability to change day and night temperatures may also be advantageous. Work on DIF (the differential temperature between day and night) has shown that raising night temperature and lowering daytime temperatures can control gibberellin activity and so reduce cell growth. In addition to this the controlled environment of a cold store would enable the use of supplementary lighting which could be used to modify the red : far red ratio and so effect the phytochrome growth response.

It may be that this knowledge of the physiological responses of plants to these conditions could be used to turn the cold store into a centre for crop growth manipulation. With further research it may be that use of techniques evolving from the knowledge of the phytochrome and gibberellin responses in plants could alleviate the present difficulties involved in storing some species when in bud or flower.

9.5 Lessons Already Learned in the Use of Cold Stores

This review has helped to pull together much of the knowledge that exists on the use of cold stores. There is still a lot to learn about the use of cold stores for container-grown HONS but some lessons can already be learned. Getting the temperature right and consistent is important, but what is the right temperature? The Dutch typically use –2ºC wherever they can whereas UK growers seldom store below 0ºC. Further work is required into which is the best temperature to use but the potential for growth and problems rises with the temperature.

Relative humidity (RH) is still an important factor for container-grown plants despite the fact the roots are surrounded with moist growing media. The Dutch recommend RH levels of 90% but there is a fine balance between high enough RH and the threat of disease spread from excessive moisture. Further work is required on RH to assess how critical a factor this is.

Most growers using cold storage maintain a clean environment and do not introduce diseased plants into the store. It is important that plants susceptible to diseases like *Botrytis* and *Rhizoctonia* are sufficiently protected.

9.6 Future Research Work

A major aim when storing plants under low temperatures is to avoid chilling injury, but it is clear that species differ in their sensitivity. Studies into cold storage in the UK would enable the development of specific storage strategies for individual plant species. In most cases it would be necessary to compromise on the ‘ideal’ temperature as the grower will need to store several species in the same cold room. However, the evidence required to formulate successful storage strategies is not yet available and studies will need to address several parameters including species and varietal response to low temperature; optimum storage duration; and the possible requirement for a buffer period of cooling or warming to reach the desired temperature.

It is recommended that work is carried out to look at plant responses to different cold store temperatures at the same time as assessing the importance of RH. Light is another factor which could be considered as well. However, this needs to be tied into work into photoperiod to ensure the maximum benefit is achieved.

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17. Appendices

17.1 Appendix I

PESTICIDES SAFETY DIRECTORATE

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Our Ref: Call ID 1561, PRD 4042

Mr T Briercliffe
ADAS Park Farm
Ditton
Aylesford
Kent
ME20 6PE

Email: tim.briercliffe@adas.co.uk

3 October 2002

Dear Mr Briercliffe

FUNGICIDES FOR USE IN COLD STORES

I am writing in response to your request that we provide you with written confirmation of the information we gave in answer to your telephone enquiry of the 11 September 2002. Your enquiry concerned the application of fungicide products to control botrytis infection on ornamental plants when in cold storage.

I apologise for the delay in replying to your enquiry. This was because of the high number of technical enquiries we have received and low staff resource.

Firstly, I will repeat the details of your original enquiry of 11 September 2002. You spoke to my colleague Rosemary Mitchell and explained that pot grown ornamental plants are stored over the winter in cold stores at 1 to 2 degrees centigrade. You asked whether it is permissible to use fungicide products, such as 'Elvaron' or 'Rovral' on these plants while they are situated in the cold stores.

You advised Rosemary that, as well as using products under suitable on-label or Specific Off-label Approval, you also take advantage of the extrapolation of use of products allowed under the 'Long Term Arrangements for Extension of Use' (LTAEU). You clarified that you follow the requirements of the LTAEU and only extrapolate from products approved for use in protected situations.

I can confirm that a product that has on-label Approval or Specific Off-label Approval for use on protected ornamental plants, would be suitable for application to ornamentals when they are in a cold store. All of the conditions stipulated under the LTAEU must be adhered to, including the provision of an appropriate COSHH assessment.

I can also confirm that it is permissible to extrapolate from approved use on any growing crop to use on ornamental plants grown on commercial agricultural and horticultural holdings under the 'Long Term Arrangements for Extension of Use' (LTAEU). The proviso of this extension of product use is that the extrapolation is that no seed or any part of the plant, to which the application is made, is used for human or animal consumption. In addition, all extrapolations must be made from the same situation of use.

Users must be aware, however, that use of a pesticide under these arrangements is their decision and that they accept the commercial risk to the crop.

A copy of the latest version of the LTAEU (LTAEU 2002) is available on the PSD Website at the following location:

http://www.pesticides.gov.uk/applicant/aahip/aahl0205_Appendix_II.htm

You should pay particular attention to Part 3 of the 'General Restrictions' and Section 1. 'Non-Edible Crops and Plants', Part (a) of the 'Extension of Use'.

I hope this clarifies the situation for you.

Yours sincerely

Jane Simcock
Information Services Branch

17.2 Appendix II

For the purpose of obtaining quotes for a typical cold storage facility and for further information on cold storage technology the following two companies were approached.

Farm Refrigeration Ltd.
Pattenden Lane, Marden, Tonbridge, Kent, TN12 9QS
Tel: 01622 832308, Fax: 01622 832365
Email: office@farm-refrigeration.co.uk
Contact: Roy Bartlett

Eastern Counties Refrigeration Ltd.
55, Eastern Way, Bury St Edmunds, Suffolk, IP32 7AB
Tel: 01284 762818, Fax: 01284 704154
Contact: R Milner

Further advice was also received from:

International Controlled Atmosphere Ltd.
Tyler House, Morley Road, Tonbridge, Kent, TN9 1RP
Tel: 01732 771199, Fax: 01732 770191
Email: ica@ICAstorage.com, Website: www.ICAstorage.com
Contact: John Wills

We would like to thank each of these companies for all their assistance in helping to assess the feasibility of transferring their technology into the nursery stock sector.

Summary of quote from Farm Refrigeration Ltd.

25th September 2002

Dear Tim

Further to our recent telephone conversations I have pleasure in outlining below details of our recommendations for refrigeration equipment, including insulation, for a storage facility for the purposes of storing 'root stock'.

I confirm a budget figure for your recommended size of store 420m^2 (assuming 10m wide x 42m long x 3.5m high). This room would be insulated with 100mm PIR insulation to walls and 150mm PIR insulation to ceiling.

We have included for one sliding door and one personnel door, and that the ceiling panels would be suspended from the existing building.

The refrigeration equipment necessary to maintain a temperature 1/2°C within this space we estimate would need to have a refrigeration duty of 40kw.

This duty includes heat ingress through the insulation assuming a maximum ambient temperature of 30 °C and respiration from the product, also for people working in the space with electric fork trucks, also for lighting and air changes due to door openings.

The refrigeration system would comprise of one 25-hp air-cooled condensing unit operating on refrigerant R407C (long term replacement R22). Two special multi-fan ceiling-mounted coolers, purpose built for this application i.e. with appropriate amount of air volume but at low velocities. Each cooler would be complete with electric defrost facility to ensure maximum heat transfer.

We have included in our price all controls, connections, etc. including insulated copper pipe as required between the components of the plant. All electrical controls, etc including a purpose built electrical control panel, with a self explanatory legend to the fascia. This control panel would also house the temperature control facility.

The project is designed as a direct expansion system with due care given to the avoidance of dehydrating 'root stock' in the store. The plant would be fully charged with R407c, commissioned and handed over with instruction books.

Our price as detailed below has been based on the assumption that an existing building with a clear level internal floor would be available for this installation and that an electrical three phase four-wire power supply would be made available adjacent to the plant position terminating in a suitably sized switch fuse. We suggest that a 60 amp supply would be adequate.

Our budget price for the above cold store with refrigeration equipment would be in order of £69,500.00 + VAT.

I will also bring to your attention that this price includes lighting in the cold store. We had based our calculations on 300 LUX, i.e. this would need 30 off 6ft florescent fittings.

Yours sincerely

Roy G Bartlett M.INST.R.
Operations Director

31 October 2002

17 Osborne Road
Reading
RG30 2PG

For the attention of Mr Tim Briercliffe

Our Reference: **E565/09/02**

ECR

Eastern Counties
Refrigeration Ltd

55 Eastern Way
Bury St Edmunds
Suffolk IP32 7AB

Tel: 01284 762818
Fax: 01284 704154

Dear Sir,

Cold Store for Nursery Stock

Thank you for your enquiry for a chill room for containerised shrub storage.

I understand the store is to be approximately 420 m^2 and is to maintain storage temperatures in the range 1 to 3°C and relative humidity of 80-85% RH. It will be loaded with shrubs in containers up to 3 litre capacity. Storage is required from the end of November until May. I have assumed that the store can be constructed within an existing weatherproof building on a level concrete floor. To allow adequate air flow we would advise that the store should have a minimum height of 3.5 m.

Cold Store Construction

Internal Dimensions 18 m x 23.8 m x 3.5 m

Panels

The panel construction will be a sandwich of the cladding and insulation bonded and cured to give high bond strength performance. They will be a single panel construction 1.15 metres wide.

Cladding

The cladding to all exposed walls and ceiling will be 0.55 mm white foodsafe laminate. This conforms to the latest EC directives on food free finishes. To all unexposed walls 0.55 mm-backer lacquer which is polyester coated galvanised steel.

Directors:

R C Gooderham, R M Milner,
J A Ball, Mrs D M Milner

Company Registration No 1068886
VAT Registration No 102 5852 01

Continued ...

Insulation Thickness

Insulation core will be 100 mm polyisocyanurate (PIR) to walls and ceilings. This is the latest lightweight, thermally efficient panel produced to meet 30 minute fire resistance requirements.

Joints

The panels are joined by an interlocking joint system.

Sealant

All joints will be sealed with a white one-part silicone mastic. The mastic conforms to BS 5889 1980 Type B sealant.

Mouldings

We will supply and install the following: -

a) 50 x 100 floor channel.
b) 50 x 50 white PVC angle to all 90° internal wall to wall and wall to ceiling joints.
c) 50 x 250 white foodsafe laminate external angle to all 90° wall to wall and wall to ceiling joints.

Sliding Door

Quantity	One off
Clear Opening	1800 x 2100 mm
Leaf Finish	White foodsafe laminate
Leaf Insulation	100 mm PIR
Leaf Edging	Anodised aluminium
Frame Finish	Anodised aluminium
Fittings	Fermod

A flexible strip door curtain with 50% overlap will be installed within the door opening.

Fire Exit Door, Hinged

Quantity	One off
Clear Opening	800 x 2000 mm
Leaf Finish	White foodsafe laminate
Leaf Insulation	100 mm PIR
Leaf Edging	Anodised aluminium
Frame Finish	Anodised aluminium
Fittings	Fermod

Refrigeration Plant

Refrigeration plant will be a single system comprising:

- three ceiling mounted dual discharge evaporators fitted with electric defrost and condensate drain,
- one air cooled condensing unit installed in an external location with weatherproof housing,
- one electrical control panel with thermostatic controls and operator control switches.

The system is rated to meet the calculated maximum load with a 20% safety margin.
The air coolers are selected to provide an evenly distributed air flow through the whole of the store area. They will be positioned in a line down the centre of the store with air flow directed in both directions across the width of the store.
The system will provide operator controls to reduce the air flow when storage temperature is reached. The air coolers are selected to provide a 'TD' of 7ºC between store temperature and evaporating temperature to maintain 80-85% RH.
The plant will be to the following specification:

Design Requirements

Room Dimensions (internal), L x W x H		18 m x 23.8 m x 3.5 m
Insulation	Walls	100 mm PIR
	Ceiling	100 mm PIR
	Floor	150 mm concrete
Maximum Ambient Temperature		+30°C
Design Room Temperature		+1°C
Number of People		Three
Air Changes		2 per 24 hours
Product Cooling		A maximum daily loading of 500 shrubs entering the store at 12ºC
Machinery Load		Nil
Lighting Load		9 W/m^2
Respiration Load		Nominal 50 W/tonne
Calculated Required Refrigeration Capacity allowing 18 hrs per day run time and 20% safety factor		31 kW

The system will consist of the following:

Condensing Unit

No off	One
Manufacturer	Bitzer
Model	LH135/4J-22.2Y
Capacity	33 kW
Evaporating Temperature	-10°C
Ambient Temperature	32°C
Compressor Type	4 cylinder semi-hermetic
Compressor Motor Size	Nominal 22 HP
Condenser Type	Air cooled
No of Fans	2
Electrical Supply	415 V/3 phase/50 Hz
Coil Construction, Tube/Fin	Copper/aluminium
Receiver Construction	Welded steel vessel with outlet valve, sight glass and safety pressure relief valve
Receiver Capacity	30 litres
Base Frame	Welded steel
Overall Dimensions, L x W x H	1600 mm x 1000 mm x 1000 mm
Weight	360 kg
Accessories	Crankcase heater HP and LP and oil pressure safety switches Part Wind Start Oil separator Suction accumulator Head pressure control by cycling fans Weatherproof housing One step capacity regulator

Air-Coolers

No off	Three
Manufacturer	Coolers & Condensers
Model	DAS 8-64
Type	Ceiling mounted, dual discharge
Capacity	11 kW
Room Temperature	+1°C
Evaporating Temperature	-6°C
No of Fans	2 x 450 mm diam
Fan Type	Propeller
Air Volume	2.92 m^3/sec
Coil Construction, Tube/Fin	Copper/aluminium

Total Surface Area	80 m^2
Fin Spacing	6 mm
Defrost Type	Electric
Defrost Capacity	7.7 kW
Electrical Supply	415 V/3 phase/50 Hz
Casework	White stelvetite with stainless steel drip tray
Dimensions, L x W x H	2362 mm x 1549 mm x 470 mm
Weight	260 kg

Refrigeration Parts

One set of good quality refrigeration parts to include:

3 x Danfoss thermostatic expansion valve
3 x Danfoss liquid solenoid valve
1 x Liquid sight glass
1 x Liquid line drier, replaceable core type
1 x Liquid line shut off valve
1 x Charging line and valve
2 x Suction and delivery vibration eliminators
1 x Suction/liquid heat exchanger

Refrigerant and Oil

One charge of refrigerant R404A and compressor oil.

Refrigerant Pipework

One set of refrigerant pipework in refrigeration quality copper tubing with brazed joints to BS2871 part 2 installed according to the Institute of Refrigeration Standards.
Piping will be supported on cush-a-clamp type pipe clips fitted to unistrut.

Pipe Insulation

The suction gas line and suction accumulator will be insulated with ½" wall armaflex pipe insulation.

Condensate Drains

To be run in plastic tubing to a suitable drainage position.

Electrical Specification

Refrigeration Control Panel:
One electrical control panel to comprise a steel enclosure containing:

- Door interlocked mains isolator
- Main and auxiliary fuses, with spares
- Part wind start compressor contactors with overloads
- Compressor anticycle timer
- One condenser fan contactors and overloads
- Six cooler fan contactors and overloads
- Three defrost contactors
- Operator control switches for plant run/pump down and evaporator fan selection
- Full set of function indicator and fault indicator lights
- One electronic room temperature thermostat
- Defrost time clock (15 minute switching)
- Three defrost termination thermostats

Electrical Installation

All interconnecting wiring between the control panel and the refrigeration plant will be installed in PVC/SWA/PVC insulated cable. Safety isolators/stop switches will be installed adjacent to each fan.
The installation will be carried out to current IEE regulations.

Commissioning

Upon completion of the installation, the refrigeration system will be pressure tested with nitrogen, charged with refrigerant and all controls tested and commissioned. Full instructions in the use of all the equipment will be provided.

Coldstore Lighting

Thirty number five foot, twin, fluorescent fittings sealed to IP65 will be installed in the chill room suitable for operation at 0ºC.

Budget Prices

Cold store construction	**£34,200.00**
Refrigeration plant and lighting	**£24,625.00**

Exclusions

1. Provision of a mains electrical supply to our control panels and transformers.
2. Provision of waste skips for the removal of waste material if required.
3. Provision of underground condensate drainage if necessary.
4. Any builder’s work to provide a base for the condensing unit and structural steel supports for the coolers.

Note

Store Ventilation

We have assumed normal door openings will provide sufficient air changes to prevent a build up of carbon dioxide in the store. If the store is to be kept permanently shut for a long period, it would be advisable to install a small extract fan and intake louvre linked to a CO_2 monitor.

General Terms and Conditions

<u>Delivery</u>	To be agreed.
<u>VAT</u>	To be charged in addition at the rate prevailing.
<u>Terms</u>	Our standard terms and conditions of sale are to apply.
<u>Validity</u>	This quotation is valid for a period of 90 days.
<u>Warranty</u>	The equipment is subject to a 12 month warranty from date of supply, this is subject to the operation and maintenance of the equipment being undertaken in accordance with the manufacturer's and our instructions.
<u>Access</u>	We have assumed that clear, uninterrupted access to the working site will be available during normal working hours.

I trust that this proposal and specification fully meets your requirements. Should you have any queries or require any further information do not hesitate to contact me.

Yours faithfully,

R M Milner