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Pot plants: A review of experimentation on shade screens and humidification and the application of these technologies in glasshouse pot plant production in Holland, Germany and Denmark.

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CONTRACT REPORT

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SUMMARY

Shade screens are commonly employed in pot-plant greenhouses in the summer to improve the growing climate. Misting (evaporative cooling) has been more rarely used but is currently the subject of intensive experimentation at several centres in Europe.

The greenhouse energy balance in summer is complex, but frequently leads to adverse conditions for plant growth. Air temperature, visible radiation, carbon dioxide depletion and vapour pressure deficit can all reach levels which reduce plant growth and quality; for any given plant species, it is rarely possible to be sure which of these factors is/are of principle concern. In general, species are categorized as 'sun' plants (require high light levels but will not tolerate high air temperatures) or 'shade' plants (will not tolerate high light levels), but these categories are not discrete and largely reflect 'grower experience' rather than detailed experimentation.

Shade screens are used principally to limit the rise in air temperature within the greenhouse (rather than reduce light transmission to the crop). However, since most screens double as energy screens for use at night, their construction leads to an effectiveness which is frequently less than might be expected. Screen characteristics which influence the growing environment beneath include shade factor, permeability to air movement and orientation within the house. Shade screen operation is generally determined by the outside solar irradiance. There may be a good case, however, to investigate further the use of plant canopy temperature as the principle control factor.

Misting appears to have some theoretical advantages over screening for many species in that air temperature and vapour pressure deficit are reduced with little effect on light transmission to the crop. Equipment can be categorized as hydraulic high pressure, hydraulic-pneumatic or mist fan. Concerns over the transmission of Legionnaires' disease by evaporative cooling have been voiced, but risks should be non-existent given good engineering practices.

Misting, used in conjunction with a clear screen, was under intensive investigation at Aalsmeer, Holland at the time of our visit in 1992. It appears that misting frequently increases plant dry weight and size, but these can be at the expense of poor foliage colour in

some species. Misting appeared to have an adverse effect on subsequent shelf life in the 1991 trials; for *Dieffenbachia* at least, a quite opposite conclusion was reached in the 1992 trials! Effects on subsequent shelf life remains a crucial factor for future investigation.

Trials on misting at Lent, Holland, proved the stimulus for the current work at Aalsmeer. The concept was to use misting in conjunction with 'late' shading (i.e. at a high outside irradiance level). Benefits were, however, slight and equipment failures (particularly blocked nozzles) proved to be a problem. Trials in Lent are now wholly concerned with shading for begonia. One benefit of 'late' screening appears to be in giving compact plants requiring reduced applications of growth regulator chemicals. Trials on misting in conjunction with screening, using cyclamen as the test crop, were about to start in Münster at the time of our visit.

It is at Årslev, Denmark, where the most detailed studies in recent years on the effects of screens in summer have been carried out. Trials there have been done using small shaded enclosures within a large wide-span glasshouse. Commercial trials, based on Årslev principles have, however, subsequently been done on commercial holdings. The results of these emphasize how species vary in their requirements, with low shade factor and 'late' screening proving best for rose, but high shade factor and 'early' screening being best for *Saintpaulia*.

Most trials on shading show some reduction in plant dry weight, but these reductions in summer are frequently very small. It has been suggested that shading encourages larger leaves to be produced and that this, by improving light interception, compensates for reductions in light transmission to the crop. Plant colour is frequently improved by shading. Leaf damage (necrosis etc) can be ameliorated both by shading and misting.

INTRODUCTION

This report follows a visit made in May 1992 to several European research centres to see current work on the optimisation of the summer environment for pot plant production, and as a prelude to HDC-funded research starting at HRI Efford in 1993 on the use of shade screens and misting (humidification or evaporative cooling) for pot begonia production (PC/46). Funding for H.M. Kitchener (ADAS, Huntingdon) and F.A. Langton (HRI, Littlehampton) was provided by HDC; funding for A.R. Finlay was provided by HRI Efford. The report gives an overview of factors influencing the glasshouse climate in summer, the general effects of shade screens and misting on the glasshouse climate and on plant growth, technical details of screens, addresses of misting equipment suppliers and a review of recent and current European R&D on the topic.

ITINERARY

Day 1	Holland - Proefstation voor de Bloemisterij in Nederland Linnaeuslaan 2A, 1431 Aalsmeer Contact: Dr J.V.M. Vogelezang and G.E. Mulderij Subject covered: the use of shade screens and misting of the foliage plants, *Spathiphyllum*, *Nephrolepis*, Croton (*Codiaeum*), *Cordyline, Dieffenbachia, Ficus benjamina* and *Guzmania.*
Day 2	Holland - Stichting Proeftuin, Lent Vossenpelsestraat 28, 6663 Lent Contact: Miss C. de Beer Subject covered: the use of shading and misting on foliage plants and Rieger begonias
Day 3	Germany - Fachhochschule Osnabrück Oldenburger Landstrasse 24, 4500 Osnabrück Contact: Prof. Dr. F. Escher and A. Bettin Subject covered: the use of coloured screens for the production of *Cyclamen*, *Saintpaulia* and *Begonia*

Day 4 Germany - Lehr- und Versuchsanstalt für Gartenbau
Munster-Wolbeck, 4400 Münster
Contact: Frau I. Schumann and M. Richter
Subject covered: the use of screens and misting for the production of *Cyclamen.*

Day 5 Denmark - Department of Horticultural Engineering, Research Centre for Horticulture
Kirstinebjergvej 10, DK - 5792, Årslev
Contact: Dr. Niels E. Andersson
Subject covered: the general effects of shade screens on the glasshouse environment in summer.

THE GREENHOUSE ENVIRONMENT

Greenhouses are used to provide an environment for the production of high quality plants during all or most of the year. In practice, additional heating has to be supplied to achieve optimal growing temperatures, but a substantial proportion of the temperature requirement comes from solar radiant energy which is transmitted through the glazing material. The extent to which the greenhouse temperature rises above the ambient (outside) temperature is determined by the amount of radiant energy transmitted, what happens to the energy, and how much of it is retained within the structure. In the daytime in summer, the air temperature inside the greenhouse frequently rises to a level which is well above the optimum for plant growth. It is to combat this that shade screens or evaporative cooling are used.

i. The greenhouse energy balance

Approximately half of the total solar radiation reaching the greenhouse is in the wavelength range of 300 to 700 nm; that below 400 nm is ultra-violet radiation (UV), and that between 400 and 700 nm is visible light. Visible light is required for plant photosynthesis and other light-mediated processes, and this radiation (between 400 and 700 nm) is referred to as photosynthetically active radiation (PAR). The remaining 50% of total radiation is in the wavelength range of 700 to 3000 nm and is referred to as near infra-red radiation. Total radiation (300 to 3000 nm) is measured using instruments such as the Kipp solarimeter.

Glass is transparent to short-wave radiation between 400 and 3000 nm but transmission losses reduce the percentage of radiant energy actually reaching the crop. Absorption by the glass itself, reflection from the glass, the passage directly out via the side walls and obstruction by glazing bars and dirt on the surface of the glass, typically give a 30-50% reduction at the crop from that incident on the surface of the greenhouse. Transmission figures vary with type of greenhouse structure, cleanliness of the glass etc.

Radiant energy entering the structure does not directly heat the air itself. A proportion will be reflected from surfaces within the greenhouse and may pass out again. Most, however, is absorbed by the plants, growing media, benches and walkways and, by conduction, helps to maintain or raise the temperatures of these. As their temperatures rise, 'sensible' heat is lost by convection to the surrounding air. Thus, the air temperature rises. Some absorbed energy will also be re-radiated from heated surfaces as long-wave (thermal) infra-red radiation. A much greater proportion of the radiant heat absorbed by plants is, however, lost as 'latent' heat as a consequence of plant transpiration. This cools the plants and increases the water vapour content of the surrounding air. There is no direct rise in air temperature as a consequence of 'latent' heat loss, and it is because of this that the air temperature in a greenhouse in summer tends to be lower when there is a complete crop cover than when the greenhouse is empty.

Glass is opaque to the long-wave thermal radiation which is emitted from heated surfaces within greenhouses. This is the basis of the so-called 'greenhouse' effect. This effect is, however, only partly responsible for the increase in air temperature. A more significant factor is that the greenhouse is an enclosed space and heat transfer between the air inside and the air outside is reduced. Thus, air temperature increases also in polythene structures even though polythene is transparent to long-wave radiation.

Problems due to high temperatures occur in the daytime in summer because the total radiation reaching the greenhouse can be extremely high and, on an average day in June, can be expected to be up to ten times greater than on an average day in December (see Table 1). Factors affecting the daily solar radiation receipt include geographical location and weather factors such as cloud cover. Irradiance changes throughout the day, reaching a maximum on a clear day around noon. Clearly, ventilation efficiency and factors such as outside wind speed will affect the 'temperature gain'. The situation is frequently reached, however, when the energy balance is such as to cause deleterious plant stress. Some of the factors affecting energy balance are shown diagrammatically in Fig. 1.

Table 1. Total solar radiation (300-3000 nm) experienced outside the greenhouse on 'typical' days in June and December. Data based on long-term averages for HRI sites (data collated by Dr D W Hand)

	Solar radiation (MJ m^{-2} day^{-1})	
Location	June	December
Efford, Hampshire	20.65	2.46
Littlehampton, W. Sussex	19.34	2.21
East Malling, Kent	18.16	1.80
Wellesbourne, Warwicks.	18.00	1.80
Stockbridge House, Yorks.	17.35	1.59
Kirton, Lincolnshire	13.00	1.62

ii. Adverse summer environments

There are two major problems in defining adverse summer environments. First, these will differ from one species to the next, causing problems for the grower wishing to mix species within a house. Second, the interrelationships between environmental factors in greenhouses mean that it is particularly difficult to separate out the effects of individual factors. Thus, in the unshaded greenhouse in summer, there is likely to be a positive correlation between the irradiance of visible light reaching the plants at a given time, and the greenhouse air temperature. Around noon, both are likely to be at their highest and it is often far from clear which, if either, of these factors is responsible for reduced plant quality.

Under high summer irradiance conditions, temperature levels can rise well above the optima for plant growth and development, leading to reduced plant quality. It is not unusual for the net carbon assimilation rate to decline as CO_2 levels in the greenhouse become depleted; true photosynthesis is restricted but respiration continues at a high level. High solar irradiances and temperatures also lead to increases in the vapour pressure deficit (v.p.d.), despite increased rates of plant transpiration. It has been shown by a number of researchers that v.p.d. levels above 1.0 kPa (55% relative humidity at 20°C; 75% relative humidity at 30°C)

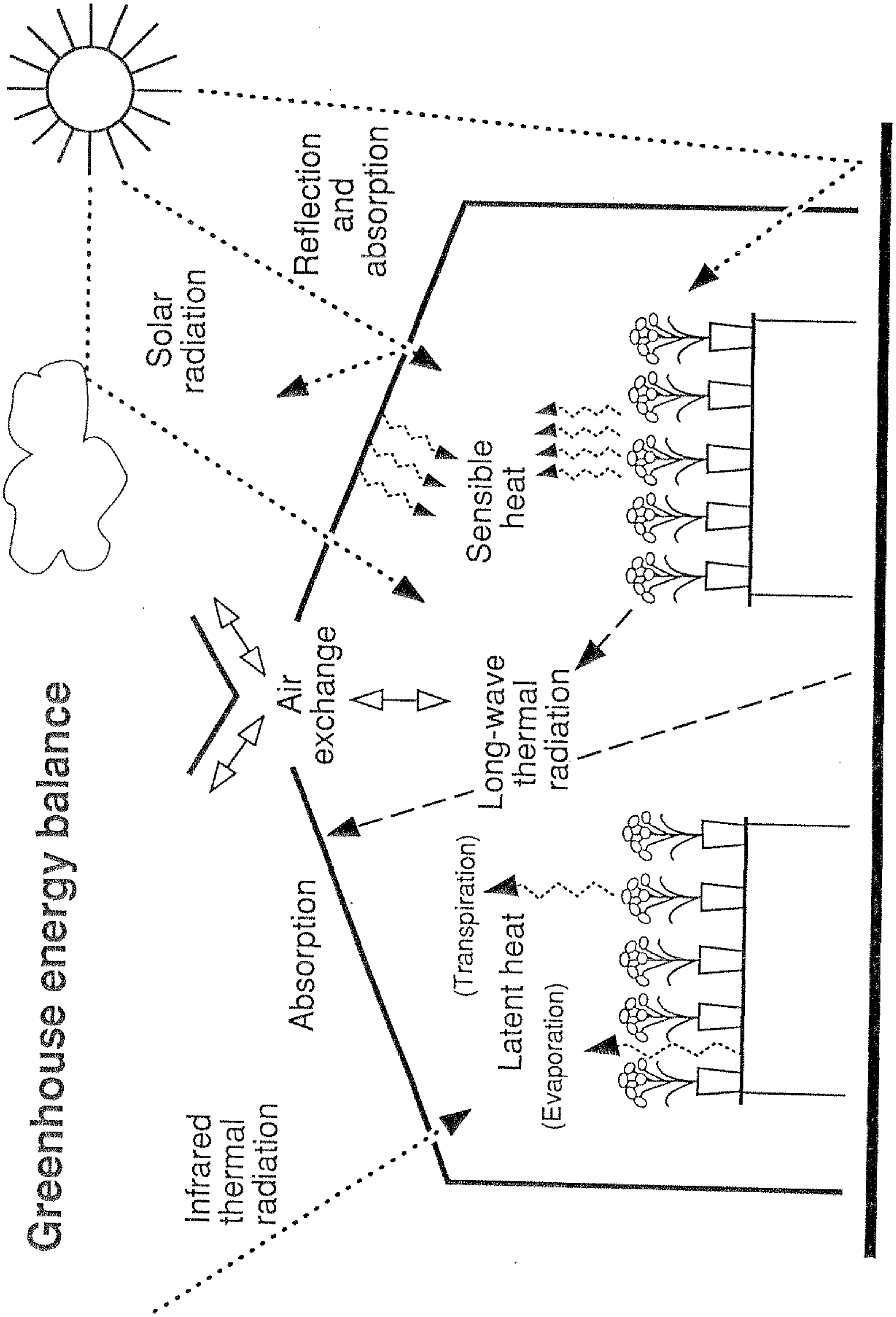

Fig. 1 Diagrammatic representation of factors affecting the energy balance in an unshaded greenhouse.

give rise to plant water stress which can have long-term detrimental effects on plant quality (Grange and Hand, 1987; Mortensen, 1986). For many species the point is soon reached when the uptake of water by the roots fails to keep pace with transpiration demand and stomatal closure occurs. This effectively curtails further transpiration and also severely restricts photosynthesis by limiting CO_2 entry to the leaf. The restriction of transpiration increases plant tissue temperature since latent heat loss is reduced. Tissue temperature can easily be 8-10°C higher than the air temperature, and temperatures as high as 35-40°C are not uncommon. Such tissue temperatures can cause irreparable cell damage. Separating out the effects of these interacting factors is extremely complicated. It is, however, important in the context of environmental optimisation to know which factors are of most concern for any given plant species.

iii. 'Sun' and 'shade' plants

In spite of the difficulties outlined above, a number of authors have commented on the relative requirements of species grown within the pot plant industry. One commonly accepted distinction is between 'sun' plants and 'shade' plants. The latter will not tolerate high levels of solar radiation; at worst, exposure to radiant energy at a level above the limit for the given species will typically cause chlorophyll breakdown by photo-oxidation, or desiccation of the leaf tissues. A list of 'sun' and 'shade' species, mainly based on grower experience, is given in Table 2. In general, the majority of flowering pot plant species require full sunlight for maximum growth (once fully established) or are, at least, relatively tolerant. Even amongst these, however, damage can be caused under extreme conditions in the unshaded greenhouse in the summer; pot chrysanthemums, for example, can develop thick, leathery, brittle, downwards-cupped dark-green leaves, believed to be due to photosynthate accumulation. *Saintpaulia* is a notable flowering pot plant exception, having only a limited tolerance of high irradiance. A generally accepted maximum level for this crop before leaf scorch can be expected is 300 Wm^{-2} total irradiance outside the greenhouse (c. 100 Wm^{-2} PAR inside). Most foliage plants are classified as 'shade' plants although crotons, for example, require high radiation levels (up to 200 Wm^{-2} PAR inside the glasshouse) to achieve intense coloration. It has to be stressed that, in general, this classification reflects 'grower experience' rather than detailed experimentation, and that there is probably a continuous gradation of tolerance levels amongst species rather than two discrete response groups as given. A further factor to be taken into account when considering tolerance to high irradiance levels is that past growing history has a major bearing; within limits, plants can become acclimatized by regular exposure to withstand higher irradiances than would otherwise be the case.

Mortensen (1991) has recently examined the responses of 15 foliage species to a range of temperatures under shaded conditions (shading to give an average irradiance equivalent to that within a south-coast greenhouse in February/March). The variation in response between species was rather large with some growing best at 18-21°C (*Saxifraga stolonifera, Begonia rex-cultorum* and *Namatanthus radicans*), but with 9 of the 15 species growing best at 24°C or higher. These latter were: *Aglaonema commutatum, Chlorophytum comosum, Codiaeum variegatum, Dracaena fragrans, Monstera deliciosa, Philodendron scandens, Rodemachera sinica, Spathiphyllum wallisii* and *Syngonium podophyllum*. Similar studies with other species (Mortensen and Larsen, 1989) showed *Hedera helix* to have a relatively low optimum temperature (c. 21°C), *Dieffenbachia maculata, Epipremnum aureum* and *Nephrolephis exaltata* to have an optimum of 24-27°C, and *Ficus elastica* and *Ficus benjamina* to have a high temperature optimum (c. 32°C). It would thus appear that many 'shade' plants are able to withstand or even prefer high temperatures so long as PAR irradiance levels are kept relatively low.

It seems likely that for many flowering pot plants, the opposite may apply. That is, they will grow best at high PAR irradiance levels combined with relatively low temperatures. Chrysanthemum is a species of this type. Flowering is delayed and flower quality and colour are poor if the average 24-hour temperature exceeds 20-22°C. On the other hand, photosynthesis will increase in direct relation to irradiance, assuming CO_2 does not become limiting, and there would seem to be every reason to attempt to maximise light receipt to boost photosynthesis if this can be managed without at the same time increasing air and tissue temperatures to 'stress' levels.

Table 2. The classification of some ornamental pot plants in relation to their tolerance of solar radiation in the greenhouse (largely based on grower experience).

Species	'Sun' plant[1]	'Shade' plant[1]
Achimenes		✓
Adiantum		✓
Aechmea	✓	
Anthurium		✓
Aphelandra		✓
Begonia		✓
Bougainvillea	✓	
Caladium	✓	
Calceolaria	✓	
Campanula	✓	
Chrysanthemum	✓	
Codiaeum	✓	
Cordyline		✓
Cyclamen	✓?	✓?
Cymbidium		✓
Dieffenbachia		✓
Dracaena		✓
Poinsettia	✓	
Ficus benjamina		✓
Ficus elastica	✓	
Fuchsia		✓
Gerbera	✓	
Guzmania		✓
Hedera		✓
Kalanchoe		✓
Maranta		✓
Nephrolepis		✓
Pelargonium (geranium)	✓	
Peperomia		✓
Philodendron		✓
Rhipsalidopsis (Easter cactus)	✓	
Saintpaulia		✓
Sansevieria		✓
Schefflera	✓	
Schlumbergera (Christmas cactus)	✓	
Sinningia (gloxinia)		✓

[1] For discussion of these terms, see text.

THE USE OF SHADE SCREENS

The essential purpose of shading in the summer is to reduce the transmission of solar radiation to the growing plants and so limit rises in air temperatures, tissue temperatures, and v.p.d.; for some plants, shading is mainly to reduce PAR irradiance. The application of opaque shading compounds directly on to the outside of the glass is an inexpensive method of achieving these objectives, and white compounds are preferred to other colours since these reflect more sunlight. The reduction in energy transmission is determined by application rate to the glass. The disadvantage of shading compounds is that PAR radiation into the house is reduced all day, every day and not just at the times of highest irradiance. This significantly reduces crop photosynthesis and generally reduces overall yield and quality compared to that in equivalent houses with variable shading.

Roller blinds on the outside of the greenhouse serve the same purpose as shading compounds and have the advantage that they can be rolled up whenever the irradiance is below some given level. They tend to be somewhat more effective in reducing internal greenhouse temperature than shading compounds since the circulation of air between the blind and the glass reduces the transfer of absorbed energy into the greenhouse by conduction. Roller blinds, however, are not well suited for use with multi-span structures or in windy conditions.

Variable shading, at least in the greenhouses of N. Europe, is more usually achieved by the use of internal screens which are pulled over the crop at fixed times, or in response to the attainment of given levels of total radiation monitored outside the greenhouse. Their effectiveness in modifying the environment around the plants depends on the characteristics inherent in the materials from which they are constructed, their method of construction and the way in which they are orientated in the greenhouse. An important consideration is that screens should occupy as small a bulk as possible when open to prevent them becoming a barrier to light transmission into the greenhouse at times of low irradiance. This, together with longevity, has an important bearing on the choice of shade material used and the method of shade screen operation.

In practice, most growers use shade screens which double as energy-saving (thermal) screens at night, and the screen material characteristics which enable this are discussed below. The use of such screens at night in summer reduces the requirement for heating to maintain optimal temperatures and, additionally, reduces the likelihood of condensation forming on the plants. Whilst tissue temperatures are frequently higher than air temperatures during the day due to the plants' absorption of solar radiant energy, the reverse is frequently the case at night due to the re-radiation of heat from the leaves to the colder glass of the greenhouse. This is particularly common under conditions of a clear night sky. When the air of the greenhouse has a low v.p.d., only a small drop in tissue temperature is required for the leaves and flowers to reach the dew point and, when this occurs, water from the warmer air will condense on the plants. This can clearly be deleterious since water films promote fungal and bacterial infection and facilitate disease spread.

i. Shade factor

It is generally agreed that for most plant species, the primary purpose of using a screen is to limit the increase in air temperature around the plants rather than to create shade *per se*. Nevertheless, screens are primarily categorised by manufacturers by their shade factor i.e. the percentage difference between incident and transmitted radiation measured using sensors mounted above and below the screen.

The ideal solar screen should reflect the sun's infra-red spectrum and have a high transmission in the PAR wavelength range (Anderson, 1991a). However, in practice, most screens reduce transmittance in the PAR wavelengths to a slightly greater extent than in the near infra-red (Nijskens *et al*, 1985). These latter workers have pointed out that screen materials should also show low absorbence of radiant energy since absorbed energy will be emitted into the greenhouse as long-wave, thermal infra-red radiation. Absorption can be particularly great for coloured screens. Low transmission in the far infra-red is also seen as a desirable characteristic since this will ensure that the screen will additionally be useful as an energy-saving screen at night. Characteristics of a coded polyester screen material and of a white woven polyethylene material tested by Nijskens *et al* (1985) are given in Table 3 to illustrate how widely screen materials vary in their 'shading' properties, and how far screens deviate from the theoretical 'ideal'. Unfortunately it is extremely difficult to obtain information of this type about screen materials currently on the market. Techniques for measuring radiation transfer through screen materials are described by Nijskens *et al* (1985) and Yates (1986).

Screens with the ideal properties for summer shading are difficult to develop but those giving a good compromise frequently combine aluminium, which is highly reflective (of all wavelengths), and polyester which has low absorption and high transmission characteristics (Table 3). The method of manufacture is frequently such that reflection from the two sides of the screen is not identical; it is important in fitting such a material to ensure that the most reflective side faces the glass.

Table 3. Radiative transfer characteristics of two coded screen materials tested by Nijskens *et al* (1985). Figures estimated from bar chart diagrams.

		%		
Material	Radiation	Transmission	Absorption	Reflection
Polyester	Total solar	64	3	33
	Visible	62	5	34
	Near infra-red	65	4	31
	Far infra-red	6	-	-
Polyethylene	Total solar	60	4	36
	Visible	55	3	42
	Near infra-red	70	3	27
	Far infra-red	58	-	-

ii. Permeability

Surprising as it may seem, Anderson (1991a) has demonstrated, using permanently shaded enclosures within a greenhouse, that closing the shade screens can frequently result in an increase in air temperature. In the absence of screens, air temperature in the greenhouse is moderated by ventilation; there is an exchange of air between that inside and that outside. When the shade screen is closed, air change through the screen material can seriously limit ventilation. Movement of air through the screen is as a result of the different densities of air above and below, resulting from differences in air temperature. Screen materials differ markedly in permeability to air with, for example, the woven acrylic DGT4b giving a four times greater exchange rate than LS14 or LS16, which are knitted materials consisting of 5mm wide polyester strips, with a proportion coated with aluminium on the upper surface (Andersson and Skov, 1991). The former has a regular array of 1 x 2 mm apertures whilst the latter pair have only randomly placed pin holes.

Trials using these three screens showed, in each case, an increase in temperature of the air below the closed screens. Against an unshaded air temperature of 27°C, DGT4b raised the air temperature to 29°C, LS14 raised it to 31°C and LS16 raised it to 30°C (Andersson, 1991a). Since the shade factors of DGT4b and LS14 are the same, the lower air temperature under DGT4b could be ascribed to its greater permeability. Permeabilities of LS14 and LS16 are the same and the lower air temperature associated with LS16 was a consequence of the higher shade factor for this material (LS14 has two strips of clear polyester for each aluminized strip, whilst LS16 has two aluminized strips for each clear strip). A beneficial aspect of using these screens, however, was that plant canopy temperature was generally 4-5°C below the air temperature in each case (see also section v.). Ludwig Svensson have now introduced the 'F' series screens to improve air exchange (see section vi.)

iii. Spectral transmission

The spectral transmission of white and transparent shade screens (with or without associated aluminized strips) can be expected to be neutral (i.e. there will be no selective wavelength absorption. Coloured screens, however, may change the spectral composition of visible light reaching the plants (Andersson, 1991b) and, by changing the ratio of red to far-red light, have a significant effect on plant morphogenesis (plant height, branching etc). This is a complex subject in its own right and this report will be restricted to a consideration of the effects of neutral screens.

iv. Orientation

It is common in Denmark, where east-west orientation, single span greenhouses are the norm, for diagonal shade screens to be installed in close proximity to the glass. These have the advantage that there is a relatively small volume of heated air above the screens to interfere with air flow through the screen material. This arrangement also offers the possibility of using split-curtains with that on south-facing surfaces having a higher shade factor than that on north-facing surfaces (Skov, 1989). Splitting the curtains at the ventilators further ensures little or no impedence to air exchange and, for all of these reasons, shade screens used for diagonal shading are frequently of non-aluminized polyester materials. Separate gable and sidewall screens are also common in Denmark with these operating as vertical roller blinds.

Vertical blinds need to be of a durable material which can be rolled into a small volume. Ideally, 'parking' of these vertical blinds should be at ground level.

Technical considerations are such that shade screens in multi-span 'Venlo-type' structures are installed horizontally, parallel to the floor of the house. These give greater impedence to air exchange and, to reduce this to a minimum, the screens should be installed as high as possible above the crop to maximize the air volume. In practice, horizontal shade screens tend to be constructed of varying proportions of 5mm aluminized and non-aluminized polyester strips.

Growers of crops which require short-day conditions for summer flowering frequently use 'gapped' black-out covers for daytime shading. The disadvantage of this is that a proportion of plants are always unshaded and can suffer high tissue temperatures. Fortunately, the actual areas of unshaded plants change through the day with 'movement' of the sun.

v. Shade screen control

In practice, conventional screen control systems operate on levels of external total radiation as measured using solarimeters. It is probably common for 'trigger levels' to be set such that the shading systems over-compensate and screen out 'useful' light. It is to be expected that higher 'trigger' levels can safely be set with 'sun' species than with 'shade' species. It is a matter of contension as to what the actual levels should be and this question has been addressed in recent research (see later).

The temperature of the plant canopy will frequently be different to that of the air temperature and it has been suggested that the operation of shade screens could be regulated on the basis of infra-red thermometers monitoring average canopy temperature (Andersson, 1990). Many factors affect the heat balance of the leaf and thus the leaf temperature. Radiative and convective energy gains are offset by re-radiation and convective losses of both 'sensible' and latent energy. The latter, by plant transpiration, can account for between 32 and 75% of energy lost by a leaf (Mellow *et al*, 1964), depending on air temperature, wind speed, vapour pressure deficit and irradiance. Clearly, screens by their influence on these factors, have a marked effect on transpiration rate and, hence, canopy temperature.

Andersson (1991c) has shown that screen shade factor for the same air change rate had little effect on the relative depression of canopy temperature below air temperature. Air change characteristics had a larger effect via influence on the air temperature; DGT4b with a high air change rate gave a lower air temperature than LS14 (same shade factor) and less convective heating of the plant foliage.

The development of remote sensing, infra-red thermometers which can be set to scan large areas of plant canopy and give an output which is the average upper-canopy temperature for the crop, opens the way to more effective control of shade screen operation. However, the apparatus is expensive and has not yet been introduced into commercial growing practice. Care would have to be taken to avoid background distortion (bench surfaces etc) and to take account of such factors as canopy age, developmental stage and pigmentation.

vi. Commercial shade-screen materials

Table 4 gives a list of coded neutral screen materials available from Ludwig Svensson BV, Marconiweg 2, 3225 LV Hellevoetsluis, Holland (Tel: 010 31 1883 22555; Fax 010 31 1883 12058), categorized by shade factor and energy saving characteristics, together with the manufacturer's recommendations as to crop type suitability.

Energy screens are of clear polyester and give a maximum of 20% shading. Screens doubling as energy screens and shade screens are, in the main, made of varying proportions of 5mm strips of clear polyester and aluminized polyester. As the proportion of aluminized polyester strips increases, so the percentage shade and percentage energy saving levels increase. The lower shade levels are more suitable for cut flowers (mainly 'sun' plants) whilst the higher shade levels are more suitable for foliage plants (mainly 'shade' plants). LS56 is rather different, being of a white polyester 'cloth-type' material. Screens purely for shading purposes ('F' series) are similar in construction to the combined energy saving and shade screens but have the clear polyester strips removed to leave gaps between the aluminized polyester strips. The advantage of this is that there is ready air exchange through the screen; this is, however, at the expense of energy saving characteristics.

Table 4. Ludwig Svensson range of shade screen materials

Code	Percentage Shade Level	Percentage Energy Saving	Suitable for
ENERGY SCREENS			
LS10	20	45	)
LS10 Plus	15	45	)
LS10 Ultra	13	43	) All plants
LS10 Ultima	14	44	)
ENERGY/SHADE SCREENS			
LS13	30	50	Carnations/roses etc.
LS14	40	50	Carnations/roses etc.
LS15	50	55	Gerberas/cyclamen/roses etc.
LS16	65	60	Freesias, Pot plants
LS17	75	65	Pot plants
LS18	85	70	Pot plants
LS56	55	43	Cut flowers, Pot plants
LS13-18	30/85	50/70	Cut flowers, Pot plants
LS Transforma	60	35	Cut flowers, Pot plants
SHADE SCREENS			
ULS 14F	40	20	Carnations, roses etc
ULS 15F	50	20	Gerberas, cyclamen, roses etc
ULS 16F	65	25	Freesias, Pot plants
ULS 17F	75	30	Pot plants
ULS 18F	85	35	Pot plants
ROLLER SCREENS			
ILS ULTRA	25	45	)
ILS 30	35	50	)
ILS 40	45	50	)
ILS 50	55	55	) All plants
ILS 60	65	60	)
ILS 70	75	65	)
ILS 80	85	70	)
ILS ALU/ALU	99.9	70	)

No responsibility is taken for the accuracy of the figures given or for product suitability.

MISTING

Misting (or fogging) as a means of evaporative cooling has potential for the improvement of the summer environment for ornamental pot plants. The use of such systems is not uncommon in commercial growing in parts of the U.S.A., particularly for rose production, but this approach has only rarely been used in N.W. Europe except to reduce plant water loss during propagation.

The concept of evaporative cooling relies on the production of a cloud of very small water droplets above the growing plants which, under high irradiance conditions, evaporate before falling onto the plants. This gives a reduction in air temperature by loss of latent heat, a reduction in v.p.d., but little reduction in PAR. Plants should remain dry and air exchange should not be restricted. Such systems ought to be particularly beneficial for 'sun' plants but not, perhaps, for 'shade' plants if high PAR irradiances (as opposed to high total irradiances) really are detrimental.

i. Equipment

Most of the commonly available systems fall into one of three types: hydraulic high pressure, hydraulic pneumatic and mist fans.

a) Hydraulic high pressure systems: These rely on the atomisation of water forced at high pressures (40-120 bar) through small orifice nozzles. Droplets tend to be large (10 micron or larger) and are not blown very far; crop wet spots are common near the nozzles. Nozzles are subject to heavy wear and tear due to the high pressures that are required and this can lead to high maintenance costs. Nozzle blockages are common and the water quality must be very good. Water filters need regular replacement.

b) Hydraulic pneumatic systems: These systems operate by blowing a mixture of water and compressed air through the delivery nozzles. High water pressures are not required but compressors are needed to supply the compressed air. Adjustment of air and water pressures gives great flexibility in water droplet size (often below 10 micron) and water usage. Dispersion into the greenhouse is good because of the effect of the compressed air and there tends to be little problem due to wet spots. Wear and tear on the nozzles are small because the water is under low pressure, and blockages are less of a problem than for hydraulic high pressure systems because nozzle orifices tend to be larger. Water quality is, therefore, less critical. The systems tend to be noisy which can be a problem.

c) Mist fan systems: These comprise groups of nozzles fitted to fans (spinning discs) which break up the water streams as they spin. Dispersion is extremely good and droplets stay airborne for a long time. High air speeds, the basis for good dispersion, mean that fans must not be placed too near the growing plants or to shade screens if plants are to remain dry. As with hydraulic pneumatic systems, noise levels can be a problem.

Systems are available which use high frequency sound waves (ultrasound) to assist the generation of water droplets. Comparison of systems is difficult, however, because there appears to be no international standard to compare efficiencies. It would be helpful for comparative purposes to have standardized measurements of droplet size at given distances from nozzles under particular conditions of v.p.d. Brief details of equipment available are given in Table 5.

ii. Legionnaires' disease

A factor which needs to be taken into account when considering the use of evaporative cooling in greenhouses is Legionnaire's disease. It has to be stressed that this respiratory disease is uncommon and its occurence depends on a complex chain of events leading to infection taking place. Nevertheless, many outbreaks have been associated with air-conditioned buildings with evaporative cooling.

The primary agent responsible for Legionnaires' disease is the water-borne bacterium, *Legionella pneumophila*, although three other species of *Legionella* have also been implicated. Multiplication of the bacterium is favoured by temperatures of 35-37°C although many 'environmental' isolates (as opposed to 'clinical' isolates) have been found which grow best at c. 30°C. Multiplication requires a pH of 6.0-7.0, a supply of organic nutrients and traces of metalic elements, particularly iron. Multiplication rates decline at higher temperatures and pasteurisation starts to occur at temperatures above 46°C; survival at temperatures above 60°C is extremely brief and prolonged exposure to such temperatures will effectively eliminate the organism. The multiplication rate also slows at temperatures below 30°C and can be considered unimportant at 15°C.

Legionella species are rather common (it is claimed that up to 50% of all water supplies are sources of the bacterium) and the circumstances which favour multiplication are to be found when water is allowed to remain in a stagnant condition at appropriate warm temperatures. Thus, build-up can occur in air-conditioning cooling towers, calorifiers, hot water storage tanks etc. The use of plastics reduces multiplication rates since iron is essential for the process. Infection is by the inhalation of air-borne contaminated water droplets (although most individuals are not susceptible to infection); hence air-conditioning plants where water is atomised into ventilation ducts have proved a particular hazard. Domestic water supplies in the UK are chlorinated and are, therefore, biocidal. However, the effective chlorine content declines with storage. In industry, biocides are introduced into water supplies to reduce the risks of infection; in horticulture, such biocides could be injurious to crops.

Evaporative cooling equipment will pose no problems so long as mains water is injected directly into the systems, with surplus water running to waste. However, there are difficulties with such arrangements due to water bye-laws. Systems which use stored water should be operated to avoid water temperatures rising to critical levels (a real possibility for water stored in greenhouses in summer) and to avoid storage for more than one day before replacement. The use of iron in constructions should be avoided. It has been claimed that ultrasonic shocks are biocidal so that equipment using ultrasound for atomisation should be relatively safe. A useful account of *Legionella* in relation to the building industry is given by Brundrett (1992) although there is no specific reference to horticultural applications.

'Humidifier fever' is unrelated to Legionnaires' disease, being due to hypersensitivity to inhaled water droplets with their associated biological matter. An individual, once sensitised, reacts rapidly to further exposure showing flu-like symptoms.

Table 5. Misting equipment and suppliers.[1]

1. MicroCool Flexi Fog system supplied by SKV WaterTechniek BV, Postbus 264, Zwarteweg 161, 1430 AG Aalsmeer, Holland. Tel: 02977 25871; Fax: 02977 42146. This is a hydraulic high-pressure system and is used in current Aalsmeer experimentation.

2. Reldair Fog System supplied by Thompson Climate Control, Alkmaar, Holland. Tel: 31721 22470; Fax: 31721 55351. This is a hydraulic high-pressure system. The company also produces a Fan Fog high-pressure system.

3. Hygrofan Fogging System supplied by Tebarint UK, Unit 11A, Lineside Way, Lineside Industrial Estate, Littlehampton, W. Sussex BN17 7EH. Tel: 0903 721704; Fax: 0903 721303. This is a fan assisted, high pressure hydraulic system.

4. MJ Air Movers supplied by DGT Volmatic (UK) Ltd., Unit 5, Benner Road Industrial Estate, Warden Tree Lane, Pinchbeck, Spalding, Lincs PE11 3TZ. Tel: 0775 710683; Fax: 0775 710682. These are vertically hung, fan-assisted high pressure hydraulic systems of Danish origin. DGT also supply their own hydraulic-pneumatic systems.

5. Sonicore System supplied by Jeff Donovan Ultrasonics, 85 Riverside Park, Otley, Yks LS21 2RW. Tel/Fax: 0943 464507. This is a hydraulic-pneumatic system utilising ultrasound to break up the water droplets.

6. MacPenny Fogging System supplied by Wright Rain Ltd., Crow, Ringwood, Hants BH24 1PA. Tel: 0425 472251; Fax: 0425 472258. This is a hydraulic-pneumatic system. Mist Irrigation System Controls of Unit 18, Hightown Industrial Estate, Ringwood, Hants BH24 1ND (Tel: 0425 474614; Fax: 0425 471296) supply controllers to operate with the MacPenny nozzles.

7. Barth + Stöcklein System supplied by Barth + Stöcklein GmbH, Postfach 46 02 01, 8000 München 46, Germany. Tel: 089 3164196; Fax: 089 3164190. The company produces hydraulic-pneumatic systems.

8. Brinkman Fan Mister supplied by Brinkman UK Ltd., North Moor Lane, Cottingham, N. Humberside HU16 4JW. Tel: 0482 842123; Fax: 0482 840444. This is a fan-assisted high pressure hydraulic system. Brinkman also supply the Elka Fog hydraulic-pneumatic system but this is primarily for small-scale use as in seed germination etc.

9. MicroMist system supplied by Jon Denton Advanced Irrigation, Unit 9, Annington Commercial Centre, Annington Road, Steyning, W. Sussex. Tel/Fax: 0903 816059. This is a high pressure hydraulic system of American origin.

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[1] It is not guaranteed that this list is exhaustive and omissions should not be taken to indicate unsuitability.

CURRENT RESEARCH

Although shading is widely used to improve the growing environment for pot plants in summer, it is far from certain how best to use such systems or even, for some species, whether shading is the best solution. Vonk Noordegraaf and van den Broek (1985) at Aalsmeer, for example, showed that shading had detrimental effects in reducing plant size and fresh weight of *Codiaeum* and *Schefflera* at all times of year, but that the reductions for *Schefflera* in the summer were very small. Either sufficient light was reaching the crop to maximise photosynthesis even under shaded conditions, or other factors were limiting growth at this time of year. 'Blind' evaluation tests indicated that unshaded summer-grown *Schefflera* (noted as a 'sun' plant in Table 2) were superior to shaded plants in overall quality. In spite of reduced growth, some shading was, however, necessary for *Codiaeum* in mid-summer (also noted as a 'sun' plant in Table 2) to avoid excessive yellow pigmentation of the foliage, reductions in leaf size and too upright a habit. At all other times, shading was judged to be detrimental to both growth and quality.

Tooze (1986) reported trials at Naaldwijk, Holland, using *Saintpaulia, Codiaeum* and *Schefflera* which also demonstrated that shading in summer had few, if any, adverse effects on the rate of growth but, in some cases, improved quality. In the case of *Saintpaulia* ('shade' plant in Table 2) unshaded plants showed slight scorch; shading (up to 56%) had little effect on the time to reach 40g fresh weight. For *Codiaeum*, shading also had little effect on the time to reach 20g fresh weight, but caused larger leaves to be produced. Colour and form also improved with shading with unshaded plants receiving the lowest score in a 'blind' quality evaluation trial. Shading also restricted lateral branching in the 'Goldfinger' cultivar. In the third species, *Schefflera*, shading appeared to promote growth (time to reach 10g) and also to increase leaf size.

At the time of our visit in 1992, further experiments were in progress at Aalsmeer to test the effects of shading on a wider range of foliage species. Interest was also turning to misting as a possible means of improving the growing environment in summer without restricting light. Misting was also the main topic of discussions at Lent and Münster.

i. Aalsmeer, Holland

The current series of trials started in 1991 under the direction of G.E. Mulderij and first year results have already been reported (Mulderij, 1992a,b). Three levels of shading were compared, with and without misting, on the growth, quality and post-harvest longevity of six ebb and flood bench-grown foliage species: *Codiaeum, Cordyline, Dieffenbachia, Guzmania, Nephrolepis* and *Spathiphyllum.* In addition to a no-shade control, shading was given using an LS-14 screen (see Table 4) triggered to come over the crops at an outside total irradiance of either 300 Wm^{-2} or 600 Wm^{-2}. In all treatments, an additional clear LS-10 screen was triggered to come over the crops at an outside total irradiance of 300 Wm^{-2}. The effect of this clear screen was such that shading with LS-14 reduced irradiance in the glasshouse but had a negligible effect on air temperature and increased the v.p.d.. The no-shade control was not comparable to 'no shading' in commercial growing and any advantage of shading in reducing air temperatures in summer were not tested. This strategy did permit, however, a direct comparison of the effects of summer light levels unconfounded by simultaneous large changes in other environmental variables; tissue temperatures were not reported.

Misting was given by hydraulic high-pressure nozzles operating for 10 seconds in each two minutes. Misting was triggered at an air moisture deficit of 8g kg^{-1} (v.p.d. = c. 1.27 kPa) in the mornings and at 4g kg^{-1} (v.p.d. = c. 0.63 kPa) in the afternoons. A temperature minimum set point of 19°C was used with venting at 21°C. Average environmental conditions during the trial as a whole are given in Table 6 where it can be seen that misting reduced both the average air temperature and the average v.p.d. Average v.p.d. levels were still rather high, (as a rule of thumb, v.p.d. levels greater than 1.0 kPa are likely to cause plant stress), perhaps reflecting the extremely brief injections of mist into the glasshouse compartments and a relatively low utilisation of available bench space for growing plants. Maximum v.p.d. levels were much higher. It is not clear to what extent the effect of misting was influenced by the presence of the clear screen.

Table 6. Average environmental conditions monitored in the 1991 Aalsmeer summer trials (based on Mulderij, 1992b)

Shading[1]:	None		at 600 Wm^{-2}		at 300 Wm^{-2}	
Misting:	-	+	-	+	-	+
Average air temperature (°C)	27.3	25.6	26.8	25.0	27.2	25.5
Maximum air temperature (°C)	38.1	35.1	37.5	35.5	39.5	35.7
Average v.p.d. (kPa)[2]	1.53	1.13	1.71	1.11	1.75	1.01
Average inside irradiance (Wm^{-2})	256.8	256.8	190.5	190.5	168.9	168.9

[1] Note that LS-10 screens were additionally used in all treatments.

[2] Estimates based on published relative humidities and average air temperatures.

Species differed markedly in their responses to these environments and Table 7 presents a summary of the conclusions reached. Severe scorch was shown by *Dieffenbachia* and *Guzmania* plants and only for the latter did shading and misting give significant improvement. Misting gave improvements in growth in several of the species but some reduction in foliage colour. For the two species used in post-harvest studies, *Dieffenbachia* and *Nephrolepis*, misting adversely affected subsequent plant appearance. For *Ficus* which was grown purely as an observational crop, misting also led to inferior post-harvest quality. Beneficial effects of shading were modest, possibly indicating that for the species trialled, light was not a major factor limiting plant growth and quality in summer.

The trials in progress at the time of our visit in 1992 were designed to investigate further the effects of misting using similar procedures to 1991. Four misting regimes were in use (max. of 20 seconds in 2 minutes): no misting, misting triggered at a v.p.d. of 1.27 kPa, misting at 1.27 kPa in the mornings and 0.63 kPa in the afternoons (as per 1991), and misting whenever the v.p.d. rose to 0.63 kPa. Clear screens (LS-10) came over the crop at 300 Wm^{-2} and LS-14 screens came over at 600 Wm^{-2}. Crops being studied were *Dieffenbachia, Guzmania, Ficus benjamina* and *Nephrolepis*. The final report (Mulderij and Bulle, 1993) appears to indicate marked improvements in growth and quality due to misting in all species except *Ficus*. In marked contrast to 1991, misting proved beneficial to the shelf life of *Dieffenbachia*; misting had little influence on the shelf life of *Nephrolepis* but proved deleterious for *Ficus*.

Table 7. Effects of shading and misting in the 1991 Aalsmeer trials.

Species	Shading (reduced light but not temperature or v.p.d.)	Misting (reduced v.p.d. and temperature but not light)
Codiaeum	Reduced plant size, dry weight and leaf colour.	Reduced leaf colour but no obvious effects on plant growth.
Cordyline	Little effect on plant growth; improved leaf colour.	Little effect on plant growth; improved leaf colour.
Dieffenbachia	Reduced leaf damage - but this was still severe in the heaviest shading treatment.	Increased shoot numbers but adversely affected post-harvest quality. Gave no amelioration of leaf damage in the glasshouse, but increased the extent of damage showing up later.
Guzmania	Increased plant growth and greatly reduced leaf scorch.	Increased plant growth and greatly reduced leaf scorch.
Nephrolepis	Markedly increased plant size but not dry weight.	Markedly increased plant size and dry weight. Adversely affected post-harvest appearance.
Spathiphyllum	No obvious effects on growth.	Improved growth.

ii. Lent, Holland

Trials on shading and misting at Lent, an experimental centre funded 50:50 by growers and government, began in 1988 with initial concentration on foliage species, but now on begonias. Misting was first applied by the use of low pressure Tegtmeyer nozzles but these gave large water droplets and wet crops, and were replaced in 1989 by a high-pressure hydraulic Reldair system. However, blockages in the nozzles of this have appeared to have been a problem in spite of water filtering and softening such that 'no clear results' had come from the begonia trials in 1991 and misting was not being used when we visited in 1992.

The 1989 trials with *Cordyline, Dracaena, Dieffenbachia* and *Spathiphyllum* (as an observation crop only), have been reported by Verberkt (1990). The three treatments adopted were: 1, shading with LS-15 (see Table 4) at an outside, total irradiance of 350 Wm^{-2}; 2, shading with combinations of LS-13 and LS-15 to give stepped shading levels at outside irradiances of 350, 636 and 1000 Wm^{-2}; 3, shading at 636 Wm^{-2} with LS-15 combined with misting. Misting came into action when the outside total light reached 350 Wm^{-2} so long as the air temperature was at least 24°C and the moisture deficit had reached 5g kg^{-1} (v.p.d. = c. 0.79). Over the course of the trials, spraying times and intervals were both gradually reduced to 30 seconds in an attempt to give constant climates and dry crops.

Misting had a much greater effect than shading in reducing air temperatures and v.p.d., but permitting a higher light transmission to the plants in combination with misting (treatment 3) gave no marked advantages in growth for the species tested. Leaf colour was paler for *Dieffenbachia, Dracaena fragans* and *Spathiphyllum* in this treatment, but misting markedly increased the width and intensity of red pigmentation in the marginal stripes of *Cordyline* 'Red Edge'. In general, higher light plus misting gave plants with increased percentage dry matter.

Trials in 1990 (Verberkt and de Beer, 1991) were with *Cordyline, Spathiphyllum* and *Syngonium* and had the following treatments: 1, shading at 250 Wm^{-2} (total, outside) and no misting; 2, shading at 250 Wm^{-2} with misting; 3, shading at 500 Wm^{-2} with misting. In each case, shading was with LS-15, and misting was applied at an outside irradiance of 200 Wm^{-2} so long as the air temperature was above 22°C and the moisture deficit greater than 5g kg^{-1} (v.p.d. = c. 0.79). The duration of mist 'bursts' was set according to the magnitude of the difference between the moisture deficit set value and the actual value with a maximum of 50 seconds per 1 minute cycle. It was clear in comparing treatments 1 and 2 that misting had relatively little influence on average 24 hour temperature or v.p.d. but, especially on hot days, gave much lower temperature and v.p.d. maxima. 'Late-shading' (treatment 3) delayed flowering in *Spathiphyllum*, possibly as a result of higher tissue temperatures; misting had no clear influence on this character. Treatment effects on growth were small, but 'late-shading' gave pale foliage in *Spathiphyllum*; this effect was not noticed for *Syngonium*.

The same treatments as in 1990 were applied in 1991 with begonia but, as noted above, system failures spoilt the experiment. Trials with begonia in 1992 were wholly concerned with shading, using LS-15 screens triggered at outside total irradiances of either 250, 400 or 500 Wm^{-2}. It was claimed that 350 Wm^{-2} is a more usual commercial 'trigger-level' for begonias in Holland. All plants were given a two hour temperature drop before 'dawn'. It was already clear at the time of our visit that 'late-screening' was giving shorter plants requiring reduced applications of growth regulator chemicals.

iii. Osnabrück and Münster, Germany

The visit to Osnabrück was a disappointment in that shading trials had been discontinued. The emphasis had been on the use of coloured screens for plant habit modification in summer, but the results had been far from conclusive. The researchers there thought it likely that the screens they had been using had been having little effect in modifying the light spectrum reaching the plants, with most of the light passing unfiltered through the shade mesh. Emphasis in habit modification had passed to the use of digital potentiometers to regulate watering in bench ebb and flood systems. The visit to Osnabrück did, however, lead to a 'last-minute' visit to Münster where trials on summer misting for cyclamen production were about to start. We had previously been unaware of these.

The misting system being installed at Münster was a low-pressure hydraulic-pneumatic type utilising ultrasound. Control was linked to relative humidity in the glasshouse but was being planned to operate in relation to glasshouse air temperature. Consideration was being given to the installation of a fan to improve fog distribution in the house. It was planned to use misting in combination with screens since it was believed on commercial experience that cyclamen could not tolerate an irradiance greater than 200 Wm^{-2} total in the house (regardless of temperature and v.p.d.), and that the required relative humidity level of 85% would not be attained by misting without screens. Screen operation was by Kipp solarimeters mounted inside the glasshouse compartments. Trials were expected to begin the following month in June.

iv. Årslev, Denmark

By far the most detailed studies in recent times of the effects of screens on the summer glasshouse environment have been carried out by Niels Andersson at Årslev. Much of what is written in this report on the theoretical implications of using screens stems from discussions at Årslev and Andersson's published work (see References). It should be noted, however, that all of the Danish trials have been done in wide-span glasshouses and, since air volumes are so important in any consideration of the effects of screens, some of his general conclusions may need verification for Venlo-type structures. There were no plans to extend the studies to misting since Andersson believed that v.p.d. levels were generally below stress levels in greenhouses in Denmark, and evaporative cooling to reduce air temperatures can only be effective up to the point where the air is near saturated and not thereafter.

General experimentation had used *Ficus pumula* as the standard crop and it was believed that this itself had had a marked influence on the findings. Other crops would have had other influences. It was believed that the substrate and watering system used had had little influence since the substrate area was so small compared to that of the internal air-filled spaces within the leaves.

Recent commercial trials had been conducted in Denmark with rose and *Saintpaulia*. In the case of rose (a 'sun' plant, Table 2), light shading (64% including glasshouse structure) had given better results than heavy shading (84%). Rose plants had been more compact, had produced more side shoots (= cut stems) and had shown more rapid flowering in the former regime. In this trial, screening was triggered at an outside total irradiance of 350 Wm^{-2}. In a follow-up trial, where trigger levels of 200, 350 and 500 Wm^{-2} were compared, rose production had benefitted from 'late screening'.

Light shading (64%) had proved detrimental for *Saintpaulia* (a 'shade' plant, Table 2), since the leaf colouration was too pale; this factor was of greater concern than time to flower which was delayed by heavy shading. A final recommendation was for 75% shading (including the glasshouse structure) for this crop. 'Early screening' was also preferred for *Saintpaulia* (at 200 wm^{-2}) to get good leaf colour, a high number of leaves and flowers per plant and rapid production.

v. General conclusions

It is still far from clear which of the various interacting environmental factors or combinations of factors are most responsible for impaired growth and quality in summer. The basic problem of greenhouse experimentation is that changes in one factor are always associated with changes in others. In general, therefore, much of the experimentation has been 'system' driven and the conclusions are at best, confused. It seems a pity that tissue temperatures have been so little monitored. The view was frequently expressed that control of shading/humidification on the basis of tissue temperature was impracticable. This may be so, but monitoring of tissue temperatures might well have been beneficial in explaining some of the results observed.

The various trials make it clear that the summer environment needs to be adjusted to match the species being grown. Most species show some reduction in growth (as determined by dry weight analyses) as a consequence of shading, although on a percentage basis, the reductions in summer are small compared to those at other times of year. Reductions in dry weight also seem rarely to be apparent in terms of final plant appearance or size and there would appear to be few examples of plants which one can clearly say are best grown without shading in summer; *Schefflera* may be one such. It is highly probable, of course, that experimenters have chosen to work with plant species which are known by growers to require some protection in summer and so the trial results reported here should not be taken to indicate that true 'sun' species really are extremely rare.

It is clear, however, that most of the plant subjects under investigation did benefit from some form of solar protection. Leaf size was frequently increased with shading and it has been suggested that this is a response which underlies the rather small decreases in dry weight accumulation. Perhaps the most general improvement given by shading was enhanced leaf colour leading to improved plant quality. This may well be a direct response to lower light levels since these effects were given by shading in the Aalsmeer trials where reductions in light were not accompanied by marked reductions in either air temperature or v.p.d. Photo-degradation of chlorophyll is not an uncommon phenomenon.

Some species have a tendency to show leaf scorch symptoms (e.g. *Dieffenbachia* and

Guzmania) but it is probable in these instances that factors other than light are playing a part. Overall it was interesting to see so many examples given in accompanying reports to show that shading had little influence on air temperature and v.p.d. As Andersson (1991a) has pointed out, this is probably associated with screen construction and with attempts to combine both energy saving and solar protection features. Poor screen orientation in relation to Venlo-type structures must also be a factor.

Misting clearly did have significant effects in reducing air temperatures and v.p.d. although the overall performance of the experimental systems observed was disappointing. The installation at Lent was clearly prone to blocked nozzles, and that at Aalsmeer looked to be insufficient for the purpose. The system being fitted in Münster seemed to be very good but there were no technical data available from which to judge its performance. In general, the philosophy underlying most of the trials seen was to use misting in combination with 'late-screening' (or with clear energy screens) to give somewhat higher light transmission than usual but combined with lower air temperatures or v.p.d. levels. It was generally believed that misting by itself would be insufficient to replace screening. The results of using this strategy at Lent were disappointing, but benefits were revealed in the Aalsmeer trials, particularly in 1992. However, the alarming inconsistencies of the 1991 and 1992 Aalsmeer trials with regard to the effects of misting on post-harvest quality indicate that this is clearly a factor which requires further careful study before any recommendations for misting can be given.

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